91-03530/

Ministry of
Northern Development
and Mines
Ontario

Aggregate Resources Inventory of
Collingwood Township
Grey County

Ontario Geological Survey
Aggregate Resources Inventory
Paper 87

By Staff of the Engineering and Terrain Geology Section,
Ontario Geological Survey, Ministry of Northern Development
and Mines

1991

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ISSN 0708–2061
ISBN 0-7743-6475-0

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Toronto, Ontario M7A 1N8

Canadian Cataloguing in Publication Data

Main entry under title:
Aggregate resources inventory of Collingwood Township, Grey County

(Ontario Geological Survey aggregate resources inventory paper, report, ISSN 0708-2061 , 87)
ISBN 0-7743-6475-0

1. Aggregates (Building materials)—Ontario—Collingwood (Township) I. Ontario Geological Survey. Engineering and Terrain Geology Section. II. Ontario. Ministry of Northern Development and Mines. III. Series.

TN939.A33 1991 553.6'2'0971318 C91-092510-0

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Parts of this publication may be quoted if credit is given. It is recommended that reference be made in the following form:

Ontario Geological Survey 1991. Aggregate resources inventory of Collingwood Township, Grey County; Ontario Geological Survey, Aggregate Resources Inventory Paper 87, 50p.

500–91–Maracle

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ABSTRACT

This report includes both an inventory and evaluation of sand and gravel as well as bedrock resources in Collingwood Township. The report is part of the Aggregate Resources Inventory Program for townships designated under the Aggregate Resources Act.

In Collingwood Township, 6 beach deposits containing sand and gravel have been selected for possible resource protection at the primary level of significance. The Selected Sand and Gravel Resource Areas occupy 830 acres (335 ha), exclusive of licenced areas. An estimated 690 acres (280 ha) are currently available for extraction, containing possible resources of 19 million tons (17 million tonnes). The parts of the selected areas which are available for extraction represent 5% of the total area occupied by the sand and gravel deposits in the township and 5% of the original tonnage.

In addition to these primary areas, several other deposits have been selected as Resource Areas of Secondary Significance. These include 3 ice-contact deposits and 5 beach deposits. Most of these secondary areas are located in the northern part of the township along the Nottawasaga Bay shoreline. Because of the limited number of primary deposits in Collingwood Township, and an expected increase in aggregate demand, these secondary areas should be considered an important part of the township's total aggregate supply.

Several bedrock formations of Middle to Upper Ordovician, and Lower to Middle Silurian age underlie the township. The Amabel Formation is a valuable potential source of crushed stone, concrete aggregate, building stone, and is also used as raw material in the manufacture of lime. Where the drift cover is less than 25 feet (8 m) thick, the Amabel Formation has been selected for possible resource protection. The Selected Bedrock Resource Area contains approximately 1680 million tons (1520 million tonnes) of bedrock resources.

Selected Resource Areas are not intended to be permanent, single land use units which must be incorporated in an official planning document. They represent areas in which a major resource is known to exist. Such Resource Areas may be reserved wholly or partially for extractive development and/or resource protection within the context of the official plan.

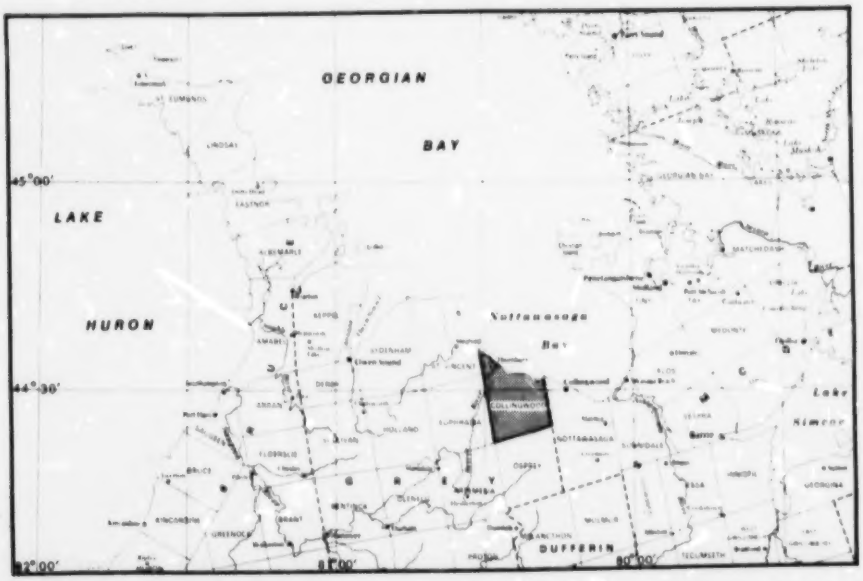


Figure 1. Key map showing the location of Collingwood Township, scale 1:1 800 000.

Résumé

Ce rapport comprend à la fois un inventaire et une estimation des ressources en sable et gravier ainsi que du substratum rocheux dans le Canton de Collingwood. Le rapport fait partie du programme sur l'inventaire des ressources en agrégat pour les cantons inclus dans la Loi sur les Ressources en agrégat.

Dans le canton de Collingwood, 6 dépôts de plage contenant du sable et du gravier ont été sélectionnés pour une éventuelle réserve de ressources de première importance. Les zones de sable et gravier sélectionnées représentent une surface de 830 acres (335 ha), à l'exclusion des zones sous licence. Une surface de 690 acres (280 ha) environ est actuellement disponible pour l'exploitation avec des réserves possibles de l'ordre de 19 millions de tonnes (17 millions de tonnes métriques). Les parties des zones sélectionnées disponibles pour l'exploitation représentent 5% de la surface totale occupée par les dépôts de sable et gravier dans le canton et 5% également du tonnage original.

En plus de ces zones de première importance, d'autres dépôts ont été choisis en tant que zones de ressources d'importance secondaire. Celles-ci comprennent 3 dépôts de contact glaciaire et 5 dépôts de plage. La plupart de ces zones secondaires se situent dans la partie nord du canton le long du littoral de Nottawasaga Bay. En raison du nombre restreint de dépôts d'importance primaire dans le canton de Collingwood et d'une croissance anticipée de la demande en agrégats, ces zones secondaires devraient être considérées comme une part importante de l'ensemble des ressources en agrégat dans le canton.

On trouve plusieurs formations rocheuses de l'Ordovicien moyen à supérieur et du Silurien inférieur à moyen dans le canton. La Formation d'Amabel représente une source excellente de pierre concassée, d'agrégat pour le béton et de pierre de construction; la roche est aussi utilisée comme matériau de base dans la production de la chaux. Là où l'epaisseur de la couverture de sédiments glaciaires est inférieure à 25 pieds (8 m), la Formation d'Amabel a été choisie comme reserve éventuelle de ressources. La zone sélectionnée pour les ressources de son substratum contient environ 1680 millions de tonnes (1520 tonnes métriques) de ressources.

Les zones sélectionnées pour leurs ressources ne sont pas destinées à un seul usage permanent requérant leur incorporation dans un document officiel sur la planification. Elles représentent des zones dans lesquelles une ressource importante a été reconnue. De telles zones à ressources peuvent être réservées en totalité ou partiellement pour l'exploitation et/ou en tant que réserve de ressources dans le cadre du plan officiel.

Aggregate Resources Inventory of Collingwood Township Grey County

by Staff[1] of the Engineering and Terrain Geology Section

1. Project Supervisor: I. Szoke and D.W. Scott, field work and report by L. Looker, compilation and drafting by Staff of the Aggregate Assessment Office. Assistance with review provided by the Resident Geologist of the Southwestern District of the Ministry of Northern Development and Mines. The Staff of the Owen Sound District Office of the Ministry of Natural Resources assisted in the collection of data, field checking and review of this report.

Manuscript accepted for publication by the Chief, Engineering and Terrain Geology Section, June 7, 1989. This report is published with the permission of V.G. Milne, Director, Ontario Geological Survey.

Introduction

Mineral aggregates, which include bedrock-derived crushed stone as well as naturally formed sand and gravel, constitute the major raw material in Ontario's road-building and construction industries. Very large amounts of these materials are used each year throughout the Province. For example, in 1987, the total tonnage of mineral aggregates extracted was 156 million tons (142 million tonnes), greater than that of any other metallic or nonmetallic commodity mined in the Province (Ontario Ministry of Northern Development and Mines 1989).

Although mineral aggregate deposits are plentiful in Ontario, they are fixed-location, nonrenewable resources which can be exploited only in those areas where they occur. Mineral aggregates are characterized by their high bulk and low unit value so that the economic value of a deposit is a function of its proximity to a market area as well as its quality and size. The potential for extractive development is usually greatest in urban fringe areas where land use competition is extreme. For these reasons the availability of adequate resources for future development is now being threatened in some areas.

Comprehensive planning and resource management strategies are required to make the best use of available resources, especially in those areas experiencing rapid development. Such strategies must be based on a sound knowledge of the total mineral aggregate resource base at both local and regional levels. The purpose of the Aggregate Resources Inventory is to provide the basic geological information required to include potential mineral aggregate resource areas in planning strategies and official plans. The reports should form the basis for discussion on those areas best suited for possible extraction. The aim is to assist decision-makers in protecting the public well-being by ensuring that adequate resources of mineral aggregate remain available for future use.

This report is a technical background document, based for the most part on geological information and interpretation. It has been designed as a component of the total planning process and should be used in conjunction with other planning considerations, to ensure the best use of a municipality's resources.

The report includes an assessment of sand and gravel resources as well as a discussion on the potential of bedrock-derived aggregate. The most recent information available has been used to prepare the report. As new information becomes available, revisions may be necessary.

Part I — Inventory Methods

FIELD AND OFFICE METHODS

The methods used to prepare the report primarily involve the interpretation of published geological data such as bedrock and surficial geology maps and reports (see References) as well as field examination of potential resource areas. Field methods include the examination of natural and man-made exposures of granular material. Most observations are made at quarries and sand and gravel pits located from records held by the Ontario Ministry of Transportation, the Ontario Geological Survey, and by Regional and District Offices of the Ontario Ministry of Natural Resources. Observations made at pit sites include estimates of the total face height and the proportion of gravel- and sand-sized fragments in the deposit. Observations are also made of the shape and lithology of the particles. These characteristics are important in estimating the quality and quantity of the aggregate. In areas of limited exposure, subsurface materials may be assessed by hand augering and test pitting, supplemented by test hole drilling, and geophysical surveys using hammer seismic equipment. The symbols for and locations of sample sites, test hole sites, and geophysical traverse lines are noted on Map 1.

Deposits with potential for further extractive development or those where existing data are scarce, are studied in greater detail. Representative layers in these deposits are sampled in 25- to 100-pound (11 to 45 kg) units from existing pit faces or from test pits. The samples are analysed for grain size distribution, and in some cases absorption, Los Angeles abrasion, and Magnesium Sulphate soundness tests and petrographic analyses are carried out. Analyses are performed either in the laboratories of the Soils and Aggregates Section, Engineering Materials Office, Ontario Ministry of Transportation, or in the Geoscience Laboratory, Ontario Geological Survey.

The field data are supplemented by pit information on file with the Soils and Aggregates Section of the Ontario Ministry of Transportation. Data contained in these files include field estimates of the depth, composition, and "workability" of deposits, as well as laboratory analyses of the physical properties and chemical suitability of the aggregate. Information concerning the development history of the pits and acceptable uses of the aggregate is also recorded. The location, size, and depth of extraction of pits licenced under the Aggregate Resources Act are obtained from records held by Regional and District Offices of the Ontario Ministry of Natural Resources. The cooperation of the above-named groups in the compilation of inventory data is gratefully acknowledged.

Aerial photographs at various scales are used to determine the continuity of deposits, especially in areas where information is limited. Water well records, held by the Ontario Ministry of the Environment, are used in some areas to corroborate deposit thickness estimates or to indicate the presence of buried granular material. These records are used in conjunction with other evidence.

Topographic maps of the National Topographic System, at a scale of 1:50 000, are used as a compilation base for the field and office data. The information is then transferred to a base map, also at a scale of 1:50 000. These base maps are prepared by the Surveys, Mapping and Remote Sensing Branch, Ontario Ministry of Natural Resources with information taken from maps of the National Topographic System by permission of Energy, Mines and Resources Canada, for presentation in the report.

RESOURCE TONNAGE CALCULATION TECHNIQUES

SAND AND GRAVEL RESOURCES

Once the interpretative boundaries of the aggregate units have been established, quantitative estimates of the possible resources available can be made. Generally, the volume of a deposit can be calculated if its areal extent and average thickness are known or can be estimated. The computation methods used are as follows. First, the area of the deposit, as outlined on the final base map, is calculated in acres. The thickness values used are an approximation of the deposit thickness, based on the face heights of pits developed in the deposit or on subsurface data such as test holes and water well logs. Original tonnage values can then be calculated by multiplying the volume of the deposit by 2500 (the density factor). This factor is approximately the number of tons in a one-foot (0.3 m) thick layer of sand and gravel, one acre (0.4 ha) extent, assuming an average density of 110 pounds per cubic foot (1766 kg/m^3).

Tonnage = Area x Thickness x Density Factor

Tonnage calculated in this manner must be considered only as an estimate. Furthermore, such tonnages represent amounts that existed prior to any extraction of material (i.e., original tonnage) (Table 1, Column 4).

The Selected Sand and Gravel Resource Areas in Table 3 are calculated in the following way. Two successive subtractions are made from the total area. Column 3 accounts for the number of acres unavailable because of the presence of permanent cultural features and their associated setback requirements. Column 4 accounts for those areas that have previously been extracted (e.g., wayside and abandoned pits are included in this category). The remaining figure is the area of the deposit currently available for extraction (Column 5). The available area is then multiplied by the estimated deposit thickness and the density factor (Column 5 x Column 6 x 2500) to give an estimate of the sand and gravel tonnage

(Column 7) presently available for extractive development and/or resource protection.

Reserve estimates are calculated for deposits of primary significance. Reserve estimates for deposits of secondary and tertiary significance are not calculated in Table 3, however the aggregate potential of these deposits is discussed in the report.

BEDROCK RESOURCES

The method used to calculate resources of bedrock-derived aggregate is much the same as that described above. The areal extent of bedrock formations overlain by less than 50 feet (15 m) of unconsolidated overburden is determined from bedrock geology maps, drift thickness and bedrock topography maps, and from the interpretation of water well records. The measured extent of such areas is then multiplied by the estimated quarriable thickness of the formation, based on stratigraphic analyses and on estimates of existing quarry faces in the unit. In some cases a standardized estimate of 60 feet (18 m) is used for thickness. Volume estimates are then multiplied by the density factor (the estimated weight in tons of a one-foot (0.3 m) thick section of rock, one acre (0.4 ha) in extent).

Resources of dolostone are calculated using a density factor of 165 pounds per cubic foot (2649 kg/m^3) or 3600 tons per acre (8070 tonnes per hectare). Sandstone resources are calculated using a density estimate of 146 pounds per cubic foot (2344 kg/m^3) and shale resources are calculated with a factor of 150 pounds per cubic foot (2408 kg/m^3).

UNITS AND DEFINITIONS

Although most of the measurements and other primary data available for resource tonnage calculations are given in Imperial units, Metric units have also been given in the text and on the tables which accompany the report. The Metric equivalent of the data is shown in brackets after or directly below the corresponding Imperial figures. Data are generally rounded off in accordance with the Ontario Metric Practice Guide (Metric Committee 1975).

The tonnage estimates made for sand and gravel deposits are termed possible resources (*see* Glossary, Appendix B) in accordance with terminology of the Ontario Resource Classification Scheme (Robertson 1975, p.7) and with the Association of Professional Engineers of Ontario (1976).

Part II — Data Presentation and Interpretation

Three maps, each portraying a different aspect of the aggregate resources in the municipality, accompany the report. Map 1, "Distribution of Sand and Gravel Deposits", gives a comprehensive inventory of the sand and gravel resources in the report area. Map 2, "Selected Sand and Gravel Resource Areas", shows those deposits which are considered to represent the largest and/or highest quality resources in the area. Map 3, "Bedrock Resources" shows the distribution of bedrock formations, the thickness of overlying unconsolidated sediments, and identifies the Selected Bedrock Resource Areas.

MAP 1: DISTRIBUTION OF SAND AND GRAVEL DEPOSITS

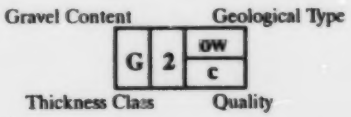
Map 1 is derived from existing surficial geology maps of the area or from aerial photograph interpretation in areas where surficial mapping is incomplete. The map shows the extent and quality of sand and gravel deposits within the study area and the present level of extractive activity.

On the map, gravel deposits are indicated by dark brown shading while sand deposits are shaded light brown. The present level of extractive activity is also indicated. Those areas which are licenced for extraction under the Aggregate Resources Act are shown by a solid outline and identified by a number which refers to the pit descriptions in Table 2. Each description notes the owner/operator, location and licenced acreage of the pit, as well as the estimated face height and percentage gravel. A number of unlicenced pits (abandoned pits or wayside pits operating on demand under authority of a permit) are identified by a numbered dot on Map 1 and described in Table 2. Similarly, test hole locations appear on Map 1 as a point symbol and are described in Table 7. Geophysics lines are shown on Map 1 by a line symbol and are interpreted in Table 8.

Map 1 also presents a summary of available information related to the quality of aggregate contained in all the known aggregate deposits in the study area. Much of this information is contained in the symbols which are found on the map. The Deposit Symbol appears for each mapped deposit and summarizes important genetic and textural data. The Texture Symbol is a circular proportional diagram which displays the grain size distribution of the aggregate in areas where bulk samples were taken.

DEPOSIT SYMBOL

The Deposit Symbol is similar to those used in soil mapping and land classification systems commonly in use in North America. The components of the symbol indicate the gravel content, thickness of material, origin (type), and quality limitations for every deposit shown on Map 1. These components are illustated by the following example:



This symbol identifies an outwash deposit 10 to 20 feet (3 to 6 m) thick containing more than 35% gravel. Excess silt and clay may limit uses of the aggregate in the deposit.

The "gravel content" and "thickness class" are basic criteria for distinguishing different deposits. The "gravel content" symbol is an upper case "S" or "G". The "S" indicates that the deposit is generally "sandy" and that gravel-sized aggregate (greater than 4.75 mm) makes up less than 35% of the whole deposit. "G" indicates that the deposit contains more than 35% gravel.

The "thickness class" indicates a depth range which is related to the potential resource tonnage for each deposit. Four thickness class divisions have been established as shown in the legend for Map 1.

Two smaller sets of letters, divided from each other by a horizontal line, follow the thickness class number. The upper series of letters identifies the geologic deposit type (the deposit types are summarized with respect to their main geologic and extractive characteristics in Appendix C) and the lower series of letters identifies the main quality limitations that may be present in the deposit as discussed in the next section.

TEXTURE SYMBOL

The Texture Symbol provides a more detailed assessment of the grain size distribution of material sampled during field study. These symbols are derived from the information plotted on the aggregate grading curves found in the report. The relative amounts of gravel, sand, and silt and clay in the sampled material are shown graphically in the Texture Symbol by the subdivision of a circle into proportional segments. The following example shows a hypothetical sample consisting of 30% gravel, 60% sand, and 10% silt and clay:

MAP 2: SELECTED SAND AND GRAVEL RESOURCE AREAS

Map 2 is an interpretative map derived from an evaluation of the deposits shown on Map 1. The deposits identified on Map 2 are those which are considered to be im-

portant in ensuring an adequate resource base for the future.

All the selected sand and gravel resource areas are first delineated by geological boundaries and then classified into three levels of significance: primary, secondary and tertiary. All such deposits are shown by dark red shading on Map 2.

Deposits of secondary significance are indicated by light red shading on Map 2. Such deposits are believed to contain significant amounts of sand and gravel. Although deposits of secondary significance are not considered to be the "best" resources in the report area, they may contain large quanitities of sand and gravel and should be considered as part of the aggregate supply of the area.

Areas of tertiary significance are outlined on the map by a solid line but have no shading. They are not considered to be important resource areas because of their low available resources, or because of possible difficulties in extraction. Such areas may be useful for local needs but are unlikely to support large-scale development.

Selected Sand and Gravel Resource Areas of primary significance are not permanent, single land use ~~units which~~ must be incorporated in an official planning document. They represent areas in which a major resource is known to exist. Such Resource Areas may be reserved wholly or partially for extractive development and/or resource protection within the context of the official plan.

The process by which deposits are evaluated and selected involves the consideration of two sets of criteria. The main selection criteria are site specific, related to the characteristics of individual deposits. Factors such as deposit size, aggregate quality, and deposit location and setting are considered in the selection of those deposits best suited for extractive development. A second set of criteria involves the assessment of local aggregate resources in relation to the quality, quantity, and distribution of resources in the region in which the report area is located. The intent of such a process of evaluation is to ensure the continuing availability of sufficient resources to meet possible future demands.

SITE SPECIFIC CRITERIA

Deposit Size

Ideally, selected deposits should contain available sand and gravel resources large enough to support a commercial pit operation using a stationary or portable processing plant. In practice, much smaller deposits may be of significant value depending on the overall reserves in the rest of the municipality. Generally, deposits in Class 1 [greater than 20 feet (6 m) thick], and containing more than 35% gravel are considered to be most favourable for commercial development. Thinner deposits may be valuable in municipalities with low total resources.

Aggregate Quality

The limitations of natural aggregates for various uses result from variations in the lithology of the particles composing the deposit, and from variations in the size distribution of these particles.

Four indicators of the quality of aggregate may be included in the deposit symbols on Map 1. They are: gravel content (G or S), fines (C), oversize (O) and lithology (L).

Three of the quality indicators deal with grain size distribution. The gravel content (G or S) indicates the suitability of aggregate for various uses. Deposits containing at least 35% gravel in addition to a minimum of 20% material greater than the 26.5 mm sieve are considered to be the most favourable extractive sites, since this content is the minimum from which crushed products can be economically produced.

Excess fines (high silt and clay content) may severely limit the potential use of a deposit. Fines content in excess of 10% may impede drainage in road subbase aggregate and render it more susceptible to the effects of frost action. In asphalt aggregate, excess fines hinder the bonding of particles. Deposits known to have a high fines content are indicated by a "C" in the quality portion of the Deposit Symbol.

Deposits containing more than 20% oversize material [greater than 4 inches (10 cm) in diameter] may also have use limitations. The oversize component is unacceptable for all concrete aggregate and for road-building aggregate, so it must be either crushed or removed during processing. Deposits known to have an appreciable oversize component are indicated by an "O" in the quality portion of the Deposit Symbol.

Another indicator of the quality of an aggregate is lithology. Just as the unique physical and chemical properties of bedrock types determine their value for use as crushed rock, so do various lithologies of particles in a sand and gravel deposit determine its suitability for various uses. The presence of objectionable lithologies such as chert, siltstone, and shale, even in relatively small amounts, can result in a reduction in the quality of an aggregate, especially for high quality uses such as concrete and asphalt. Similarly, highly weathered, very porous and friable rock can restrict the quality of an aggregate. Deposits known to contain objectionable lithologies are indicated by an "L" in the quality component of the Deposit Symbol.

If the Deposit Symbol shows either "C", "O", or "L" or any combination of these indicators, the quality of the deposit is considered to be reduced for some uses of the aggregate. No attempt is made to quantify the degree of limitation imposed. Assessment of the four indicators is made from published data, from data contained in files of both the Ontario Ministry of Transportation and the Engineering and Terrain Geology Section of the Ontario Geological Survey, and from field observations.

Quality data may also appear in Table 9, where the results of aggregate quality tests are listed by test type and sample location. The types of tests conducted and

the test specifications are explained in Appendixes B and E, respectively.

Analyses of unprocessed samples obtained from test holes, pits or sample sites are plotted on grain size distribution graphs. On the graphs are the Ontario Ministry of Transportation's gradation specification envelopes for aggregate products: Granular Base Course A, B and C, Hot-Laid Asphaltic Sand Nos. 1,2,3,4, and 8, and concrete sand. By plotting the gradation curves with respect to the specification envelopes, it can be determined how well the unprocessed sampled material meets the criteria for each product. These graphs, called Aggregate Grading Curves, follow the tables in the report.

Location and Setting

The location and setting of a resource area has a direct influence on its value for possible extraction. The evaluation of a deposit's setting is made on the basis of natural and man-made features which may limit or prohibit extractive development.

First, the physical context of the deposit is considered. Deposits with some physical constraint on extractive development, such as thick overburden or high water table, are less valuable resource areas because of the difficulties involved in resource recovery. Second, permanent man-made features, such as roads, railways, powerlines, and housing developments, which are built on a deposit, may prohibit its extraction. The constraining effect of legally required setbacks surrounding such features is included in the evaluation. A quantitative assessment of these constraints can be made by measurement of their areal extent directly from the topographic maps. The area rendered unavailable by these features is shown for each resource area in Table 3 (Column 3).

The assessment of sand and gravel deposits with respect to local land use and to private land ownership is an important component of the general evaluation process. These aspects of the evaluation process are not considered further in this report, but readers are encouraged to discuss them with personnel of the pertinent District Office of the Ontario Ministry of Natural Resources.

REGIONAL CONSIDERATIONS

In selecting sufficient areas for resource development, it is important to assess both the local and the regional resource base, and to forecast future production and demand patterns.

Some appreciation of future aggregate requirements in an area may be gained by assessing its present production levels and by forecasting future production trends. Such an approach is based on the assumptions that production levels in an area closely reflect the demand and that the present production "market share" of an area will remain roughly at the same level.

The aggregate resources in the region surrounding a municipality should be assessed in order to properly evaluate specific resource areas and to adopt optimum resource management plans. For example, a municipality that has large resources in comparison to its surrounding region constitutes a regionally significant resource area. Municipalites with high resources in proximity to large demand centres, such as metropolitan areas, are special cases.

Although an appreciation of the regional context is required to develop comprehensive resource management techniques, such detailed evaluation is beyond the scope of this report. The selection of resource areas made in this study is based primarily on geological data or on considerations outlined in preceding sections.

MAP 3: BEDROCK RESOURCES

Map 3 is an interpretative map derived from bedrock geology, drift thickness and bedrock topography maps, water well data from the Ontario Ministry of the Environment, oil and gas well data from the Petroleum Resources Section (Ontario Ministry of Natural Resources) and from geotechnical test hole data from various sources. Map 3 is based on concepts similar to those outlined for Maps 1 and 2, but displays both the inventory and evaluation on the one map.

The geological boundaries of the bedrock units are shown by a dashed line. Isolated outcrops are indicated by an "X". Three sets of contour lines delineate areas of less than 3 feet (1 m) of drift, areas of 3 to 25 feet (1 to 8 m) of drift, and areas of 25 to 50 feet (8 to 15 m) of drift. The extent of these areas of thin drift are shown by three shades of blue. The darkest shade indicates where bedrock outcrops or is within 3 feet (1 m) of the ground surface. These areas consitute potential resource areas because of their easy access. The medium shade indicates areas where drift cover is up to 25 feet (8 m) thick. Quarrying is possible in this depth of overburden and these zones also represent potential resource areas. The lightest shade indicates bedrock areas overlain by 25 to 50 feet (8 to 15 m) of overburden. These latter areas constitute resources which have extractive value only in specific circumstances. Outside of these delineated areas, the bedrock can be assumed to be covered by more than 50 feet (15 m) of overburden, a depth generally considered to be too great to allow economic extraction (unless part of the overburden is composed of economically attractive deposits).

Other inventory information presented on Map 3 is designed to give an indication of the present level of extractive activity in the report area. Those areas which are licenced for extraction under the Aggregate Resources Act are shown by a solid outline and identified by a number which refers to the quarry descriptions in Table 5. Each description notes the owner/operator, location, licenced acreage and an estimate of face height. Unlicenced quarries (abandoned quarries or wayside quarries operating on demand under authority of a permit) are also identified and numbered on Map 3 and de-

scribed in Table 5. Two additional symbols may appear on the map. An open dot indicates the location of a selected water well which penetrates bedrock. The overburden thickness is shown in feet beside the open dot. Similarly, test hole locations appear as a point symbol with the depth to bedrock shown in feet beside it. The test holes may be further described in Table 7.

SELECTION CRITERIA

Criteria equivalent to those used for sand and gravel deposits are used to select bedrock areas most favourable for extractive development.

The evaluation of bedrock resources is made primarily on the basis of performance and suitability data established by laboratory testing at the Ontario Ministry of Transportation. The main characteristics and uses of the bedrock units found in southern Ontario are summarized in Appendix D.

Deposit "size" is related directly to the areal extent of thin drift cover overlying favourable bedrock formations. Since vertical and lateral variations in bedrock units are much more gradual than in sand and gravel deposits, the quality and quantity of the resource are usually consistent over large areas.

Quality of the aggregate derived from specific bedrock units is established by the performance standards previously mentioned. Location and setting criteria and regional considerations are identical to those for sand and gravel deposits.

SELECTED RESOURCE AREAS

Selection of Bedrock Resource Areas has been restricted to a single level of significance. Three factors support this approach. First, quality and quantity variations are gradual. Second, the areal extent of a given quarry operation is much smaller than that of a sand and gravel pit producing an equivalent tonnage of material, and third, since crushed bedrock has a higher unit value than sand and gravel, longer haul distances can be considered. These factors allow the identification of alternative sites having similar development potential. The Selected Areas, if present, are shown on Map 3 by a line pattern and the calculated available tonnages are given in Table 6.

Selected Bedrock Resource Areas shown on Map 3 are not permanent, single land use units which must be incorporated in an official planning document. They represent areas in which a major bedrock resource is known to exist. Such Resource Areas may be reserved wholly or partially for extractive development and/or resource protection within the context of the official plan.

Part III - Assessment of Aggregate Resources in Collingwood Township

LOCATION AND POPULATION

Collingwood Township occupies 69,449 acres (28 106 ha) in the northeastern part of Grey County, in southwestern Ontario (Ontario Ministry of Municipal Affairs 1988). The township is shown on portions of the Collingwood (41 A/8), Nottawasaga (41 A/9) and Owen Sound (41 A/10) map sheets of the National Topographic System, at a scale of 1:50 000.

The total population of Collingwood Township was 2689 in 1985, an increase of 9% since 1975 (Ontario Ministry of Municipal Affairs 1988; Ontario Ministry of Treasury, Economics and Intergovernmental Affairs 1976). The majority of the inhabitants are rural-residential or rural-farm residents. Well-drained soil types, and proximity to Georgian Bay and the sheltering Niagara Escarpment resulting in a more reliable frost-free season (Chapman and Putnam 1984), combine to support different types of agricultural activities. Specialization in apple production, with an emphasis on Mackintosh and Northern Spy apples, is carried out in the Beaver Valley near Thornbury and Clarksburg.

In recent years, a number of recreational developments has significantly increased the seasonal population. A large number of seasonal inhabitants support the recreational ski industry which is located along the Niagara Escarpment. In addition, there has been an increase in rural nonfarm development within commuting distance of the town of Collingwood in neighbouring Nottawasaga Township, Simcoe County. Similar growth patterns may be expected in the near future, and will result in an increased demand for sand and gravel resources for both road building and general construction requirements.

Thornbury is the largest town in Collingwood Township. The town's population in 1985 was 1434, an increase of 13% since 1975 (Ontario Ministry of Municipal Affairs 1988; Ontario Ministry of Treasury, Economics and Intergovernmental Affairs 1976). The other major population centre within the township is the settlement of Clarksburg, located south of Thornbury on the Beaver River. Smaller unincorporated settlements scattered throughout the township include Heathcote, Camperdown, Craigleith, Banks, Gibraltar, Red Wing and Ravenna. The nearby town of Collingwood (population 12,035 in 1985) in the County of Simcoe also provides major commercial, industrial and institutional services to the surrounding population (Ontario Ministry of Municipal Affairs 1988).

Road access to the township is provided by King's Highway 26, which follows the shoreline of Nottawasaga Bay, and by an irregular grid network of paved county and gravel-surfaced township roads. The grid network is interrupted by many swampy areas, and by the Niagara Escarpment. Access up and down the escarpment is limited to a few routes. A line of the Canadian National Railways runs parallel to King's Highway 26 and connects Thornbury to destinations in the south.

PHYSIOGRAPHY AND SURFICIAL GEOLOGY

The physiography of Collingwood Township and the distribution of surficial materials, including sand and gravel deposits shown on Map 1, are the result of both preglacial erosion, and of glacial activity which took place in the Late Wisconsinan Substage of the Pleistocene Epoch (known informally as the "Great Ice Age"). The Late Wisconsinan lasted from approximately 23,000 to 10,000 years ago and was marked by the repeated advance and melting back of extensive, continental ice sheets.

During this time, Collingwood Township was covered by the Georgian Bay ice lobe. As this ice lobe melted northward over the plateau in the central part of Grey County, a series of recessional moraines were deposited, each representing a major standstill of the melting ice margin. This area is part of the Horseshoe Moraines physiographic region (Chapman and Putnam 1984). The region is characterized by a complex series of till ridges, kame moraines, outwash plains, and meltwater channels, interspersed with till plains and drumlins. Many small lakes, streams and numerous swampy areas are present. Within Collingwood Township, the main features of this physiographic region are the Gibraltar and Banks recessional moraines.

The two arms of the Gibraltar Moraine meet at a point north of the hamlet of Gibraltar. The eastern arm follows the edge of the Niagara Escarpment to the Pretty River Valley, where the moraine becomes obscured in a mass of ice-contact stratified drift (Burwasser 1974a). The west limb of the Gibraltar Moraine extends to the southwest as a continuous ridge from Gibraltar to the Osprey Township border. Here the arm of the moraine consists of very sandy, bouldery Newmarket Till deposited around bedrock knobs and interspersed with ice-contact sands and gravels (Burwasser 1974a). Meltwater erosion has reshaped the moraine along this western limb, and extensive outwash deposits were deposited along its flanks. The ice-contact and outwash features associated with this arm of the moraine are of limited value as aggregate sources because they are mainly shallow deposits of variable quality with generally low gravel contents.

The Banks Moraine is the most northerly of the recessional moraines. Although it is not as well developed as the Gibraltar Moraine, it is otherwise very similar (Chapman and Putnam 1984). Only a small section of the ridge from Banks to Kolapore is clearly defined. The

moraine consists of clayey silt till that is rich in Queenston Formation shale fragments (Burwasser 1974a). This clayey silt till is localized within the study area, and occurs generally near the edge of the escarpment and extensively on the north side of the Banks Moraine. The tills are not acceptable for use as aggregate because they contain excessive amounts of fines. Numerous ice-contact and outwash deposits are associated with the Banks Moraine, although none are suitable for high-quality aggregate use.

The Niagara Escarpment is the most dominant feature in the township, separating the Horseshoe Moraines and the Beaver Valley physiographic regions (Chapman and Putnam 1984). The escarpment face developed as a result of differential erosion. The erosion-resistant Amabel Formation dolostone forms the cap rock of the Niagara Escarpment, and overlies softer and more easily eroded shales. As the shale is weathered away, the dolostone is undermined, and eventually blocks break away leaving a steep scarp. The steepest part of the Niagara Escarpment occurs in Collingwood Township between Craigleith and Camperdown (Chapman and Putnam 1984). This section of the Escarpment has the highest elevation in southern Ontario, rising over 1000 feet (305 m) above Georgian Bay (Chapman and Putnam 1984), and is well known for its ski runs and associated development.

The Beaver Valley physiographic region occupies a sharply cut indentation in the Niagara Escarpment which was once a deep preglacial river valley (Chapman and Putnam 1984). As glacial ice advanced up this shale-floored re-entrant valley, it smoothed off any protruding spurs, leaving a valley with a broad base and very steep sides. The Beaver River has cut its own valley in the bedrock floor of the re-entrant valley for approximately 25 miles (40 km) from Thornbury southwest to Flesherton (Artemesia Township).

Below the escarpment in the Beaver Valley is a flat lacustrine plain consisting mainly of sediments deposited by glacial Lake Algonquin and post-glacial Lake Nipissing. Glacial Lake Algonquin, and subsequently, post-glacial Lake Nipissing formed as the Wisconsinan ice melted back and proglacial meltwaters ponded against the receding ice sheet. Glaciolacustrine and lacustrine clay and silts were deposited in areas of deeper and quieter water in these lakes, while predominantly silty fine sand was deposited in the nearshore, shallow water areas. A large crescent-shaped lacustrine plain is located in the Thornbury area. The clays and silts are unsuitable for aggregate use and the sand is usually too fine-grained for use in most road-building and construction aggregate products.

Beach deposits, generally containing fine to coarse gravel derived from local bedrock and glacial till, are found along the ancestral lake shorelines in the township. A prominent glacial Lake Algonquin shore bluff extends inland across the northern part of the township around the nose of the Blue Mountains. The large beach deposit near Clarksburg, located at the 725- to 775-foot (221 to 236 m) elevation, was formed by glacial Lake Algonquin. This beach deposit in the Clarksburg area has been a traditional source of aggregate for road-building and general construction purposes.

The lower beach deposits at the 635-foot (194 m) elevation were formed by glacial Lake Nipissing. Post-Nipissing to modern-day beach deposits occur below the 625-foot (190 m) elevation along the Nottawasaga Bay shoreline.

Post-glacial erosional and depositional processes have been of minor importance in modifying the physiography of the township. Recent alluvial sediments of sand and silt are present along the banks of the rivers, brooks and creeks in Collingwood Township. These sediments are not considered acceptable for aggregate use. In some poorly drained areas and depressions, swampy and marshy conditions have developed.

EXTRACTIVE ACTIVITY

In 1971, Collingwood Township was designated under the Pits and Quarries Control Act and is now designated under the Aggregate Resources Act. Prior to that time, a number of pits had been operating on a casual basis throughout the township. Nineteen pits for which data is available have been identified in this report and their locations are shown on Maps 1 and 2. Many of the pits are now inactive or overgrown.

At the time of writing there are 11 pits licenced for extraction under the Aggregate Resources Act. The total area of all the licenced properties in Collingwood Township is 529.5 acres (214.3 ha). Annual production records on file at the Owen Sound District Office of the Ontario Ministry of Natural Resources indicate that the average annual production from licenced pits in the township from 1972 to 1986 was approximately 297,413 tons (269 813 tonnes).

A large part of Collingwood Township lies within the policy areas of the Niagara Escarpment Commission. The boundaries of the policy areas must be observed, as extraction in these areas is restricted and subject to the policies established by the Commission.

SELECTED SAND AND GRAVEL RESOURCE AREAS

Map 1 illustrates all of the surficial deposits which contain sand and gravel in Collingwood Township. Unlike the aggregate- rich townships of southern Grey County, Collingwood Township lacks large deposits of high quality sand and gravel but does contain approximately 14,000 acres (5700 ha) of sand and gravel deposits. The total estimated tonnage in these deposits is 370 million tons (355 million tonnes). Many of these deposits are not suitable for large-scale extraction because of deposit size and extent, and thickness and quality of the material. Consequently, only the most significant sources are suggested for possible resource protection.

Map 2 illustrates the sand and gravel deposits selected for possible resource protection. Six beach depos-

its have been selected as Sand and Gravel Resource Areas of Primary Significance. The primary resource areas cover approximately 830 acres (355 ha), exclusive of licenced properties. An estimated 690 acres (280 ha) are considered to be available for extraction, containing approximately 19 million tons (17 million tonnes) of sand and gravel. The available portions of the primary resource areas represent 5% of the total area of sand and gravel deposits in Collingwood and 5% of the total tonnage.

Aggregate suitability data obtained from the Ministry of Transportation indicate that the pits identified within the resource areas contain aggregate suitable for a wide variety of road-building and general construction products. A major constraint affecting the quality of the aggregate in these pits is the presence of soft shales and calcareous siltstones. These materials occur in varying amounts within the resource areas and can restrict the use of the aggregate. Clay seams and zones of cemented gravel have also been observed in several pits. Without extensive processing, excessive fines can limit high-specification use of the material.

Channel face samples taken in the licenced properties by staff members of the Owen Sound District Office of the Ontario Ministry of Natural Resources were analyzed for grain size distribution, soundness, absorption and lithology by the Materials Testing Laboratories of the Soils and Aggregates Section of the Ministry of Transportation in London, Ontario. The results of the tests on these samples are shown in Table 9. The specification limits for each test are included in Appendix E of this report. Granular Base Course petrographic numbers ranged from 101.1 to 217.8. The hot-mix and concrete petrographic numbers ranged from 115.2 to 342.5. Unacceptable values may be largely attributed to the presence of undesirable material such as shale and siltstone.

Magnesium Sulphate Soundness and Absorption tests were also performed on the licenced pit samples. The results of the Magnesium Sulphate Soundness test are expressed as a percent weight loss, whereas the results of the test for absorption are expressed as percent weight gained. The percent weight loss during the Magnesium Sulphate Soundness test for the coarse fraction of the samples was 2.3 to 16.8, generally within the specification ranges for most products. Percent weight loss results for the fine fraction of the sampled aggregate varied considerably. When subjected to absorption testing, samples taken from the licenced pits had weight gains of 1.45 to 2.57%.

Selected Sand and Gravel Resource Area 1

Selected Sand and Gravel Resource Area 1 consists of 4 glacial Lake Algonquin beach and nearshore bar deposits, labelled 1a, 1b, 1c and 1d on Map 2. Together the deposits occupy approximately 750 acres (305 ha).

Area 1a is the largest of the deposits, and has been extensively developed for aggregate extraction. Seven licenced and two unlicenced pits have been developed in Area 1a. Face heights in the pits ranged from 5 to 25 feet (1.5 to 8 m) and generally contained well rounded, fine to coarse gravel interstratified with medium to coarse sand with frequent seams of fine sand and silt. Soft shales and calcareous siltstones were noted in some of the pits, and cementation of material was common. Field estimates of gravel content ranged from 30 to 70% gravel.

Samples of the material from pit nos. 1, 2, 4, 6 and 7 contained between 29 and 70% gravel, and the samples taken from pit nos. 1 and 7 appeared to be suitable for crushing (Figures 2a to 4b). The aggregate has been used for a wide range of road-building and general construction products. Coarse aggregate reserves are, however, generally of poor quality because of a high shale content. The sand fraction is generally of good quality and is suitable for many asphaltic paving mixes. Although aggregate quality data are lacking for Areas 1b, 1c and 1d, the aggregate will likely be of similar quality to that found in Area 1a.

After deletions for licenced areas, cultural constraints and previous extractions, Selected Resource Area 1 has approximately 630 acres (255 ha) currently available for aggregate extraction. Based on average deposit thicknesses of 10 to 12 feet (3 to 4 m), the deposits contain an estimated 18 million tons (16 million tonnes) of sand and gravel. The resource area is easily accessible from various paved county roads which connect with King's Highway 26.

Selected Sand and Gravel Resource Area 2

Selected Sand and Gravel Resource Area 2 consists of two Lake Nipissing beach deposits, labelled 2a and 2b on Map 2. The deposits are located immediately southeast of the town of Thornbury and are separated by Indian Brook.

This prominent resource area rises up to 20 feet (6 m) above the adjacent lacustrine sand plain. The deposits may consist of similar quality material as found in the larger beach deposit of Area 1a. Therefore, despite the lack of subsurface data, the deposits have been selected at the primary level of significance.

Resource Area 2 occupies a total area of 79 acres (32 ha). Cultural constraints reduce the area presently available for extraction to 59 acres (24 ha). Assuming an average deposit thickness of 10 feet (3 m), possible resources of sand and gravel are estimated to be 1 million tons (1 million tonnes). Road access to the area is excellent.

Resource Areas Of Secondary Significance

Ice-contact stratified drift and lacustrine beach deposits scattered throughout Collingwood Township have been

designated as Resource Areas of Secondary Significance. Classification of these deposits as secondary resources is difficult because of the lack of subsurface data and fewer pit exposures. Many of these deposits are limited in depth, however, they add significantly to the resource base of the township and should be considered an important part of the total aggregate supply.

Three ice-contact deposits have been selected at the secondary level. The deposits lack continuity and the material they contain can be extremely variable in grain size.

Licenced pit nos. 9, 10 and 11 have been developed in an ice-contact deposit located near Gibraltar. The deposit is situated on top of the Niagara Escarpment and is associated with the Gibraltar Moraine. Faces in the pits ranged in height from 15 to 25 feet (5 to 8 m) and generally revealed angular, coarse, cobbly to bouldery gravel with fine sand. The gravel contents ranged from 30 to 70%. Pit workability problems include the presence of silt and clay seams and zones of cementation that should be avoided during extraction. Oversize material was also noted in the pits. Samples of the material from the licenced pits contained more than 50% gravel and the gravel appeared to be suitable for crushing (Figures 5a to 6b). The material may be suitable for a variety of aggregate products with appropriate processing.

A water well located in one of the two gravel ice-contact deposits near Camperdown reveals 35 feet (11 m) of gravel. Although no other subsurface data is available for these deposits, they are of a similar origin as the previously described ice- contact deposit, and may contain similar material.

Five beach deposits located along the shoreline of Nottawasaga Bay have also been selected at the secondary level. All of the deposits are narrow and relatively shallow, making them economically unsuitable for large scale extraction. Although no subsurface data are available for the deposits, they have the same type of geological origin as Selected Sand and Gravel Resource Area 1, and may contain similar quality material.

BEDROCK GEOLOGY

Collingwood Township is underlain by shales and limestones of the Middle to Upper Ordovician Lindsay, Blue Mountain, Georgian Bay and Queenston formations, as well as by strata of the Lower to Middle Silurian Clinton and Cataract Groups and the Amabel Formation. The distribution of, and the contacts between the formations are shown on Map 3. With the exception of the escarpment face, the bedrock surface is relatively flat and the formations have a gentle regional dip to the southwest. Drift thickness in the township varies from over 180 feet (55 m) west of Thornbury to zero at surface outcrops located along the brow of the Niagara Escarpment. Much of the central portion of the township is covered by less than 50 feet (15 m) of drift. The Niagara Escarpment is the dominant geological and geomorphological bedrock feature, and trends in a serrated fashion across the township from the Pretty River Valley to the hamlet of Duncan. In Collingwood Township the escarpment consists of a prominent bluff of dolostone of the Amabel Formation, and a secondary bench formed by the Manitoulin Formation of the Cataract Group.

The Lindsay Formation is the oldest bedrock unit in the township and outcrops near Craigleith along the Nottawasaga Bay shoreline. The formation has been subdivided into a lower member and the Collingwood Member (Russell and Telford 1983). The lower member consists of grey, argillaceous limestone containing numerous shaly partings, particularly in the upper portion of the unit. The rock is soft and can weather to a rubble because of its high shale content. In central Ontario the lower member has been quarried at Bowmanville for use in the manufacture of cement. The suitability of the lower member for use in the production of crushed stone products within the township can only be established by testing. The upper unit of the Lindsay Formation is called the Collingwood Member, formerly known as the Lower Member of the Whitby Formation, until it was redefined by Russell and Telford (1983). The Collingwood Member contains brownish-black, organic-rich, interbedded calcareous shale and limestone. It is generally unsuitable for use as aggregate. The Lindsay Formation has not been selected for resource protection in Collingwood Township.

The Lindsay Formation is overlain by the Upper Ordovician Blue Mountain Formation that underlies a narrow band along the Nottawasaga Bay shoreline. The formation was redefined by Russell and Telford (1983). It was previously referred to as the Upper and Middle Members of the Whitby Formation (Liberty and Bolton 1971). The Blue Mountain Formation consists of blue-grey, non-calcareous shale, which is unsuitable for use as aggregate. Shale from the Blue Mountain Formation may have potential for use in structural clay products (Martini and Kwong 1986).

The Blue Mountain Formation is overlain by the Georgian Bay Formation which consists of alternating grey carbonate beds and grey to bluish-grey shale (Liberty and Bolton 1971). In places, the formation is over 400 feet (122 m) thick and, notwithstanding minor lithologic variation, its chemical composition is fairly consistent throughout its occurrence (Vos 1975). Georgian Bay shale is a raw material used for brick manufacture by some brick plants in southern Ontario, and has also been used for the production of structural drain tile and lightweight expanded aggregate. In the township, the formation is generally covered by thick overburden, especially at the floor of the Beaver Valley and Pretty River Valley. The formation has not been selected for resource protection.

The Queenston Formation overlies the Georgian Bay Formation and consists predominantly of red shale with occasional beds of mottled green shale (Liberty and Bolton 1971). The formation underlies a broad belt paralleling the Niagara Escarpment and is exposed in numerous valleys of streams draining from the escarpment.

The Queenston shale is a resource of provincial significance for the production of structural clay products. The suitability of using Queenston shale for brick manufacture may be restricted by local concentrations of gypsum and other soluble salts, excessive lime content and unusual hardness (Guillet 1982). Testing is strongly recommended to determine the suitability of the shale for the production of structural clay products. The formation has not been selected for possible resource protection.

The Queenston Formation is overlain by a succession of erosion-resistant sandstones, shales and dolostones of the Clinton and Cataract Groups, which form the face of the Niagara Escarpment. Four formations of the Clinton and Cataract Groups outcrop in the township and they are the Whirlpool, Manitoulin, Cabot Head and Fossil Hill formations.

The Whirlpool Formation is the lower-most member of the Cataract Group and it unconformably overlies the Queenston shale. It consists of grey to grey-brown, medium-bedded, fine- to medium-grained, laminated, quartz sandstone (Telford 1976). The thickness of the unit varies from 10 to 15 feet (3 to 5 m) (Hewitt 1969), and it outcrops on the northern side of Osler Bluff. The sandstone is a well-known building stone quarried elsewhere in southern Ontario near Cheltenham under the trade name of "Credit Valley Sandstone" (Hewitt 1969). Its architectural value as a building stone is displayed in such buildings as the Royal Ontario Museum, the Main Block of the Ontario Parliament Buildings and the old Toronto City Hall (Vos 1969).

The Whirlpool Formation is overlain by the grey and bluish grey, thin- to medium-bedded, fine- to medium-crystalline dolomitic limestones and dolostones of the Manitoulin Formation. Shale partings and lenses of white chert are known to occur within this formation (Vos 1969). The unit forms the caprock of a subsidiary scarp located below the main face of the escarpment. Outcrops are common along this subsidiary scarp, particularly in the Osler Bluff and Blue Mountain regions. Dolostone from the Manitoulin Formation has been extracted from a quarry site in St. Vincent Township for base and subbase road-building aggregate. No areas have been selected for possible resource protection because of the limited lateral extent of the formation and the availability of better quality bedrock resources in the Amabel Formation dolostone.

The red, green and grey shales and limestone interbeds of the Cabot Head Formation (Telford 1976) overlie the Manitoulin Formation, and represent the upper-most portion of the Cataract Group in this area. The unit outcrops in a roadcut located approximately 2 miles (3 km) east of Ravenna. The shale is too soft for use as load-bearing aggregate. The formation is generally suitable for use as expanded aggregate, brick and tile, but it has not been used for these purposes because exposures suitable for quarrying are scarce (Vos 1969). The Cabot Head shale has not been selected for possible resource protection in Collingwood Township because of its limited extent.

The Cabot Head Formation is overlain by the thin- to medium-bedded, brown, medium-crystalline, fossiliferous dolostone of the Fossil Hill Formation, which is part of the Clinton Group. The unit outcrops poorly at the base of the main escarpment face, and is 6 feet (2 m) in thickness at a roadcut located approximately 2 miles (3 km) east of Ravenna (Telford 1976). The formation has not been selected for possible resource protection because of the availability of thicker and better quality bedrock resources in the Amabel dolostone.

The youngest bedrock unit in Collingwood Township is the Middle Silurian Amabel Formation. The formation overlies the Clinton and Cataract Groups, and forms the erosion-resistant cap rock of the Niagara Escarpment. The unit underlies a considerable upland portion of the southern part of the township. The formation within the township largely consists of massive-bedded, light grey to blue-grey, fine- to medium-crystalline, porous dolostone (Telford 1976). Minor quantities of chert may also be present, especially near the base of the formation. Chert is a deleterious material and, if present in excessively high quantity, may restrict the use of the dolostone to low grade aggregate products.

The Amabel Formation is a provincially significant aggregate source and is also suitable for the production of a wide variety of industrial mineral products. Uses of the Amabel Formation include crushed stone, concrete aggregate, building stone, and raw material for lime manufacture. Those areas of the Amabel Formation that are overlain by less than 25 feet (8 m) of drift in the township have been selected for possible resource protection.

The Amabel Formation often contains an abundance of fossil reef structures which are commonly lensoids 50 to 60 feet (15 to 18 m) in height and a few hundred feet in diameter (Hewitt 1960). In Collingwood Township, numerous reefed mounds and ridges within the unit form topographic highs on the plateau behind the escarpment (Telford 1976). The massive beds and irregular surfaces of the reefs may influence the workability of the rock, and the porous nature of the reefed dolostone could be expected to increase the absorptive characteristics of aggregate derived from it. The reef rock is generally softer and less durable than the surrounding rock, and may contain clay pockets and iron staining, particularly near the surface (Hewitt 1960). For these reasons, the quality of the reefal rock may be impaired for use as aggregate. However, the non-reefal rock (deposited between the reefs) is generally of high quality and is well suited for extraction and use. Extractive operations are therefore better situated within the non-reefal areas.

Selected Bedrock Resource Area 1

Selected Bedrock Resource Area 1 consists of all those areas where the Amabel Formation dolostone is over-

lain by less than 25 feet (8 m) of glacial sediments. The acreage and estimated reserves in Selected Resource Area 1 are presented in Table 6.

The Amabel dolostone is usually of high quality, however, porous reefal structures and chert, where encountered, may restrict some high-specification uses of the aggregate. For these reasons, the quality of the bedrock should be investigated at specific sites that are proposed for possible future quarry development before extraction begins. A significant thickness of Amabel dolostone may be suitable for quarrying, as exposures of up to 75 feet (32 m) can be observed along the face of the Escarpment (Telford 1976).

Selected Bedrock Resource Area 1 has a combined area of 8800 acres (3550 ha), of which 7800 acres (3150 ha) are presently available for extraction. Assuming an average workable thickness of 60 feet (18 m), available bedrock resources are estimated to be approximately 1680 million tons (1520 million tonnes). Considerable portions of the selected resource area located near the edge of the Escarpment lie within policy areas of the Niagara Escarpment Commission and may be unavailable for future extractive development. The resource area is easily accessible by a grid network of county and township roads.

SUMMARY

The sand and gravel deposits of Collingwood Township are the product of glacial processes which took place during the Late Wisconsinan Substage of the Pleistocene Epoch. Six beach deposits containing sand and gravel have been selected for possible resource protection at the primary level of significance. Aggregate from these deposits has been used for a wide range of road-building and general construction products. In addition, several deposits have also been selected at the secondary level in the township.

The township is underlain by shales and limestones of the Middle to Upper Ordovician Lindsay, Blue Mountain, Georgian Bay and Queenston Formations, as well as by strata of the lower to Middle Silurian Clinton and Cataract Groups and Amabel Formation. The Amabel Formation, which is the caprock of the Niagara Escarpment, is considered to be the most acceptable for extractive development. The high quality Amabel dolostone can be used for the production of a wide range of crushed stone and industrial mineral products. In areas where the drift cover is less than 25 feet (8 m), the Amabel Formation has been selected for possible resource protection. The availability of some of the bedrock resources may be restricted because they lie within the policy areas of the Niagara Escarpment Commission.

Enquiries regarding the Aggregate Resources Inventory of Collingwood Township may be directed to the Aggregate Assessment Office, Engineering and Terrain Geology Section, Ontario Geological Survey, Ministry of Northern Development and Mines at 77 Grenville St., 10th Floor, Toronto, Ontario, M7A 1W4 [Tel. (416) 965-1183], or to the Resident Geologist, Southwestern District, Mines and Minerals Division, Ministry of Northern Development and Mines, Box 5463, 659 Exeter Road, London, Ontario, N6A 4L6 [Tel. (519) 661-2796] or to the Owen Sound District Office, Ministry of Natural Resources, 611 - 9th Avenue East, Owen Sound, Ontario, N4K 3E4 [Tel. (519) 376-3860].

TABLE 1. TOTAL SAND AND GRAVEL RESOURCES, COLLINGWOOD TOWNSHIP.*

1 Class No.	2 Deposit Type (*see* Appendix C)	3 Areal Extent Acres (Hectares)	4 Original Tonnage Millions of Tons (Tonnes)
1	S-IC	530 (214)	27 (24)
	S-LP	185 (75)	12 (11)
	S-OW	35 (14)	2 (2)
2	G-IC	830 (335)	36 (33)
	G-LB	1120 (455)	32 (29)
	S-IC	630 (255)	21 (19)
	S-LB	250 (101)	7 (6)
	S-LP	2750 (1110)	106 (96)
	S-OW	1860 (750)	46 (42)
3	G-IC	1390 (560)	25 (23)
	G-LB	120 (49)	2 (2)
	G-OW	110 (45)	1 (1)
	S-IC	750 (305)	13 (12)
	S-LB	155 (63)	3 (3)
	S-LP	390 (158)	7 (6)
	S-OW	1630 (660)	21 (19)
4	S-IC	1110 (450)	8 (7)
	S-LB	145 (59)	1 (1)
	S-OW	35 (14)	< 1 (< 1)
		14,000 (5700)	370 (335)

** Identified deposit areas within the town of Thornbury, Craigleith Provincial Park, Duncan Crevice Caves Provincial Nature Reserve and Pretty River Valley Provincial Park are omitted on all tables.*

N.B. Minor variations in all tables are caused by rounding of data.

TABLE 2. SAND AND GRAVEL PITS, COLLINGWOOD TOWNSHIP.

1 NO.	2 MTO NO.	3 OWNER/ OPERATOR	4 LOT	5 CONC.	6 LICENCED AREAS Acres (Hectares)	7 FACE HEIGHT Feet (Metres)	8 % GRAVEL
LICENCED PITS							
1	N6-11	E.C. King Const. (Div. of Miller Paving)	29	11	34 (14)	10-20 (3-6)	30-70
2	N6-2	Ardiel Acres	29	11	30 (12)	5-10 (1.5-3)	30-40
3	-	Dennis Breadner	Pt. 28	11	17 (7)	10-15 (3-5)	-
4	N6-3	Bert Sadler	N1/2 27	11	35 (14)	10-12 (3-4)	35-60
5	-	Bert Sadler	S1/2 27	11	32 (13)	10-15 (3-5)	-
6	N6-4 N6-19	McKean Quarries Ltd.	27	10	140 (57)	15-25 (5-8)	30-45
7	N6-07	Township of Collingwood	26	10	58 (23)	10-12 (3-4)	30-70
8	N6-22	Allen Reekie	26	7	44.5 (18.0)	20-30 (6-9)	0-75 variable
9	C11-18	Stone Glen Const. Ltd.	7	4	19 (8)	15-20 (5-6)	35-70
10	C11-3	Ray Conn	6	4	29 (12)	15-20 (5-6)	30-60
11	-	McKean Bros. Farms Ltd.	5	4	91 (37)	20-25 (6-8)	35-65
					529.5 (214.3)		
UNLICENCED PITS							
12	N6-16	Hunter	26	10	-	10-15 (3-5)	- (overgrown)
13	N6-7	Newson	26	10	-	10-15 (3-5)	40-50 (rehabilitated)
14	N6-21	Welstead	27	9	-	15 (5)	< 35
15	-	Unknown	11	10	-	20 (6)	20-30 (partially overgrown)
16	-	Unknown	13	4	-	8-10 (2-3)	- (overgrown)
17	-	Unknown	12	3	-	8-10 (2-3)	20-30 (overgrown)
18	-	Unknown	20	2	-	12-15 (4-5)	< 5
19	-	Unknown	18	1	-	20-25 (6-8)	0

* *Abandoned pits, or wayside pits operating on demand under authority of a permit.*

TABLE 3. SELECTED SAND AND GRAVEL RESOURCE AREAS, COLLINGWOOD TOWNSHIP.

1 DEPOSIT NO.	2 UNLICENCED AREA Acres (Hectares)	3 CULTURAL SETBACKS Acres (Hectares)	4 EXTRACTED AREA Acres (Hectares)	5 AVAILABLE AREA Acres (Hectares)	6 ESTIMATED DEPOSIT THICKNESS Feet (Metres)	7 AVAILABLE AGGREGATE Millions of Tons (Tonnes)
1a	415 (168)	85 (34)	5 (2)	325 (132)	12 (4)	10 (9)
1b	130 (53)	15 (6)	0 (0)	115 (46)	10 (3)	3 (3)
1c	82 (33)	5 (2)	0 (0)	77 (31)	10 (3)	2 (2)
1d	120 (49)	10 (4)	0 (0)	110 (44)	10 (3)	3 (3)
	750 (305)	115 (46)	5 (2)	630 (255)		18 (16)
2a	64 (26)	20 (8)	0 (0)	44 (18)	10 (3)	1 (1)
2b	15 (6)	0 (0)	0 (0)	15 (6)	10 (3)	< 1 (< 1)
	79 (32)	20 (8)	0 (0)	59 (24)		1 (1)
	830 (335)	135 (55)	5 (2)	690 (280)		19 (17)

TABLE 4. TOTAL IDENTIFIED BEDROCK RESOURCES, COLLINGWOOD TOWNSHIP.

1 **DRIFT THICKNESS** Feet (Metres)	**FORMATION**	3 **ESTIMATED DEPOSIT THICKNESS** Feet (Metres)	4 **AREAL EXTENT** Acres (Hectares)	5 **ORIGINAL TONNAGE** Millions of Tons (Tonnes)
3–25 (1–8)	Amabel Formation	60 (18)	8800 (3550)	1900 (1720)
25–50 (8–15)	Amabel Formation	60 (18)	8600 (3500)	1860 (1690)
			17,400 (7000)	3750 (3400)
3–25 (1–8)	Clinton & Cataract Groups	60 (18)	4700 (1900)	1020 (920)
25–50 (8–15)	Clinton & Cataract Groups	60 (18)	840 (340)	181 (164)
			5500 (2230)	1200 (1090)
3–25 (1–8)	Queenston Formation	60 (18)	4950 (2000)	950 (860)
25–50 (8–15)	Queenston Formation	60 (18)	3350 (1360)	640 (580)
			8300 (3350)	1590 (1440)
3–25 (1–8)	Georgian Bay Formation	60 (18)	1660 (670)	320 (290)
25–50 (8–15)	Georgian Bay Formation	60 (18)	2950 (1190)	570 (520)
			4600 (1860)	890 (810)
3–25 (1–8)	Blue Mountain Formation	60 (18)	290 (117)	56 (51)
25–50 (8–15)	Blue Mountain Formation	60 (18)	1520 (620)	290 (265)
			1810 (730)	345 (315)
3–25 (1–8)	Lindsay Formation	60 (18)	1210 (490)	260 (236)
25–50 (8–15)	Lindsay Formation	60 (18)	380 (154)	82 (74)
			1590 (640)	340 (310)
			39,000 (15 800)	8100 (7300)

TABLE 5. QUARRIES, COLLINGWOOD TOWNSHIP.

1 NO.	2 MTO NO.	3 OWNER/ OPERATOR	4 LOT	5 CONC.	6 LICENCED AREAS Acres (Hectares)	7 FACE HEIGHT Feet (Metres)

-NONE-

TABLE 6. SELECTED BEDROCK RESOURCE AREAS, COLLINGWOOD TOWNSHIP.

DEPOSIT NO.	DEPTH OF OVERBURDEN Feet (Metres)	UNLICENCED AREA Acres (Hectares)	CULTURAL SETBACKS Acres (Hectares)	EXTRACTED AREA Acres (Hectares)	AVAILABLE AREA Acres (Hectares)	ESTIMATED WORKABLE THICKNESS Feet (Metres)	AVAILABLE RESOURCES Millions of Tons (Tonnes)
1	3–25 (1–8)	8800 (3550)	960 (390)	0 (0)	7800 (3150)	60 (18)	1680 (1520)

TABLE 7. SUMMARY OF TEST HOLE DATA, COLLINGWOOD TOWNSHIP.

-NONE-

TABLE 8. SUMMARY OF GEOPHYSICS DATA, COLLINGWOOD TOWNSHIP.

-NONE-

TABLE 9. AGGREGATE QUALITY TEST DATA, COLLINGWOOD TOWNSHIP.

	COARSE AGGREGATE					FINE AGGREGATE
	Petrographic Number					
Pit No.	GBC & 16 mm Crushed	Hot Mix & Concrete	Magnesium Sulphate Soundness % Loss	Absorption %	Los Angeles Abrasion % Loss	Magnesium Sulphate Soundness % Loss
1	161.4	305.8	16.8	1.87	-	21.3
2	217.8	342.5	-	-	-	13.9
4	121.3	227.9	5.6	1.47	-	10.8
6a	151.5	197.2	-	-	-	21.0
6b	160.2	207.7	-	-	-	16.0
7	160.2	194.0	8.8	1.58	-	15.2
8a	128.1	153.1	3.3	1.71	-	11.4
9	107.0	115.2	4.4	1.45	-	-
10	126.8	167.9	7.8	2.50	-	23.5
11a	104.7	132.3	2.3	1.74	-	13.7
11b	101.1	158.2	3.6	2.57	-	7.9

Source: Owen Sound District Office, Ministry of Natural Resources.

NOTE: The quality test data refers strictly to a specific sample. Because of the inherent variability of sand and gravel deposits care should be exercised in extrapolating such information to the rest of the deposit.

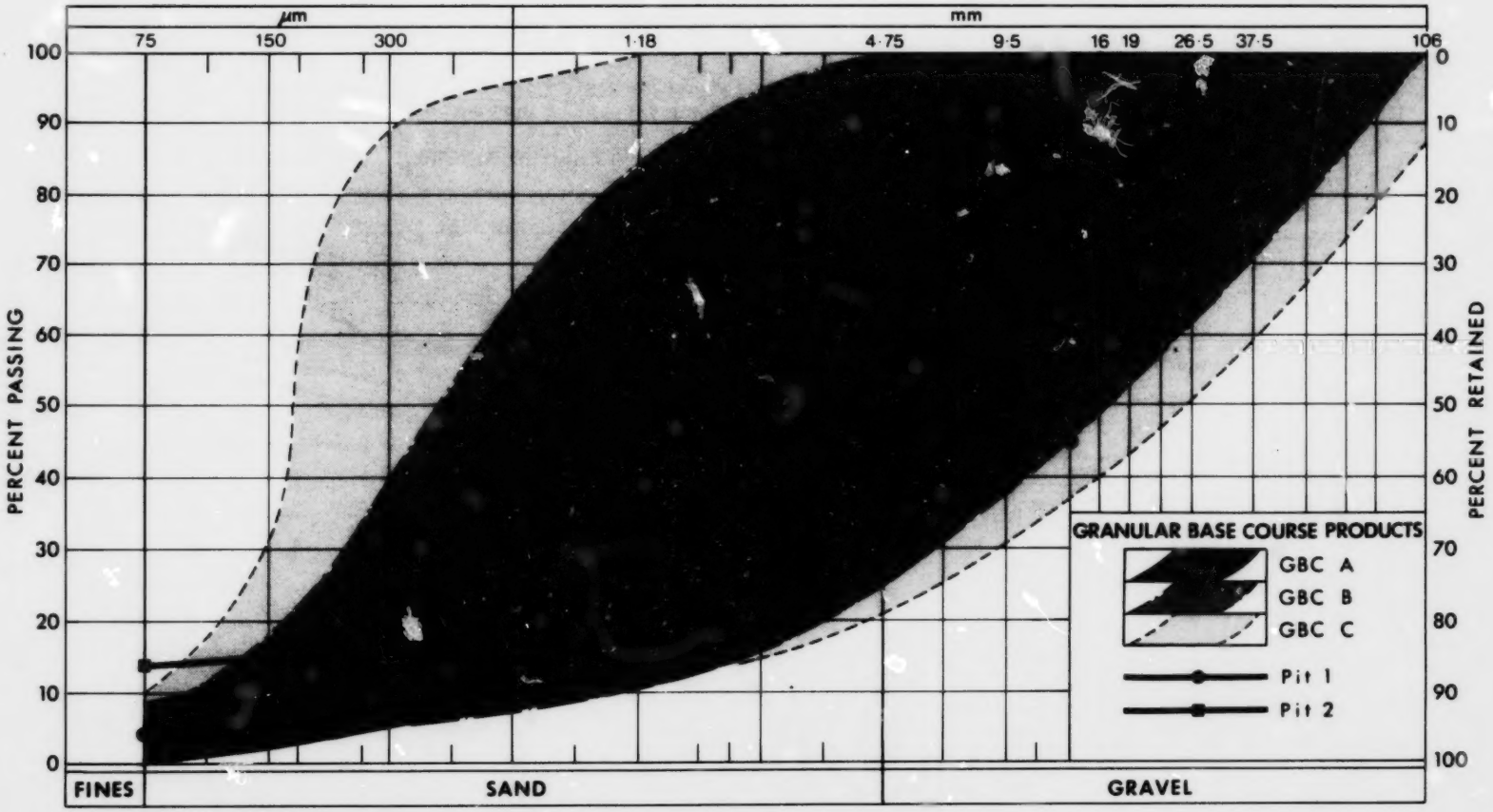


FIGURE 2a. AGGREGATE GRADING CURVES, COLLINGWOOD TOWNSHIP.

Based on analysis of the total aggregate contained in unprocessed samples (gradation envelopes adapted from M.T.O. Form 1010, 1980).

NOTE: Information portrayed by grading curves refers strictly to a specific sample taken at the time of field investigation. Due to the inherent variability of sand and gravel deposits care should be exercised in extrapolating such information to the rest of the deposit.

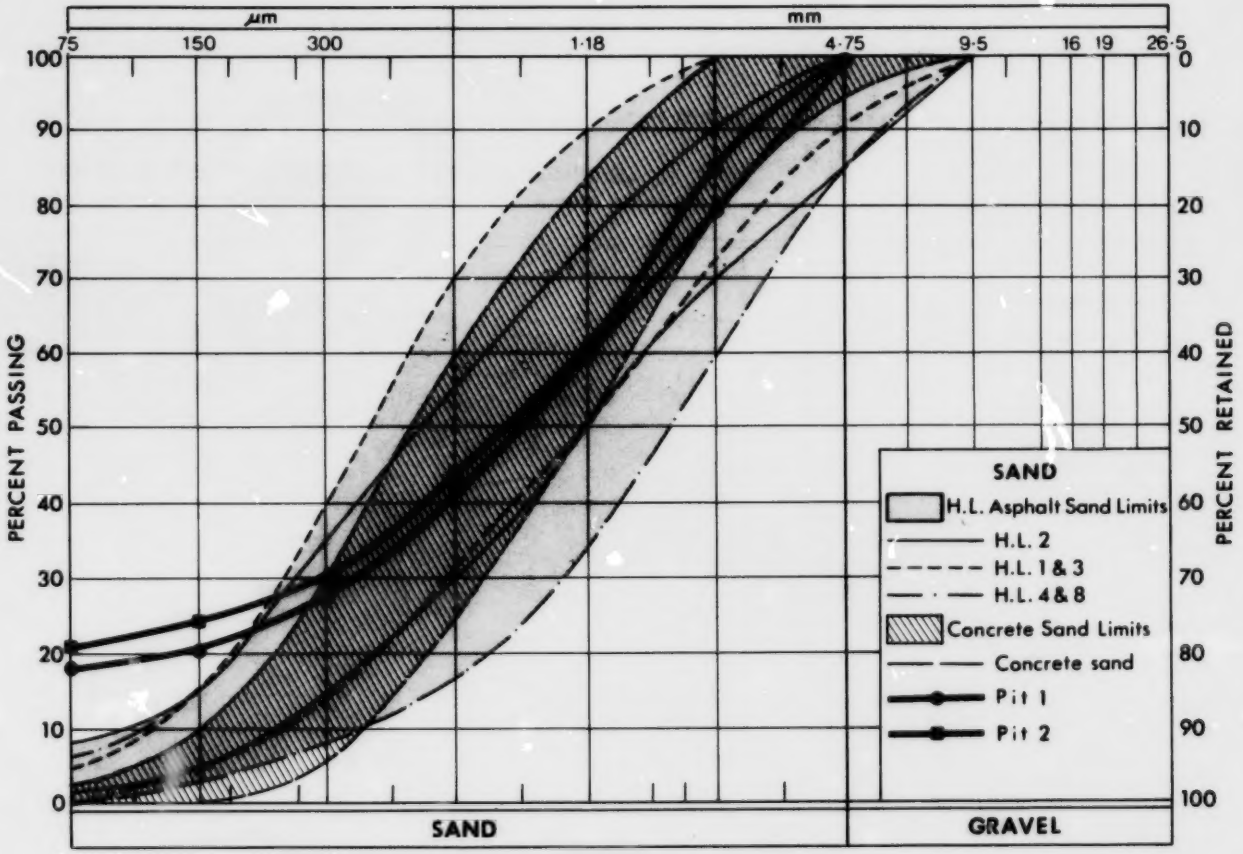


FIGURE 2b. AGGREGATE GRADING CURVES, COLLINGWOOD TOWNSHIP.

Based on analysis of the sand fraction of the aggregate contained in unprocessed samples (gradation envelopes adapted from M.T.O. Forms 1002, 1979 and 1003, 1981).

NOTE:

Information portrayed by grading curves refers strictly to a specific sample taken at the time of field investigation. Due to the inherent variability of sand and gravel deposits care should be exercised in extrapolating such information to the rest of the deposit.

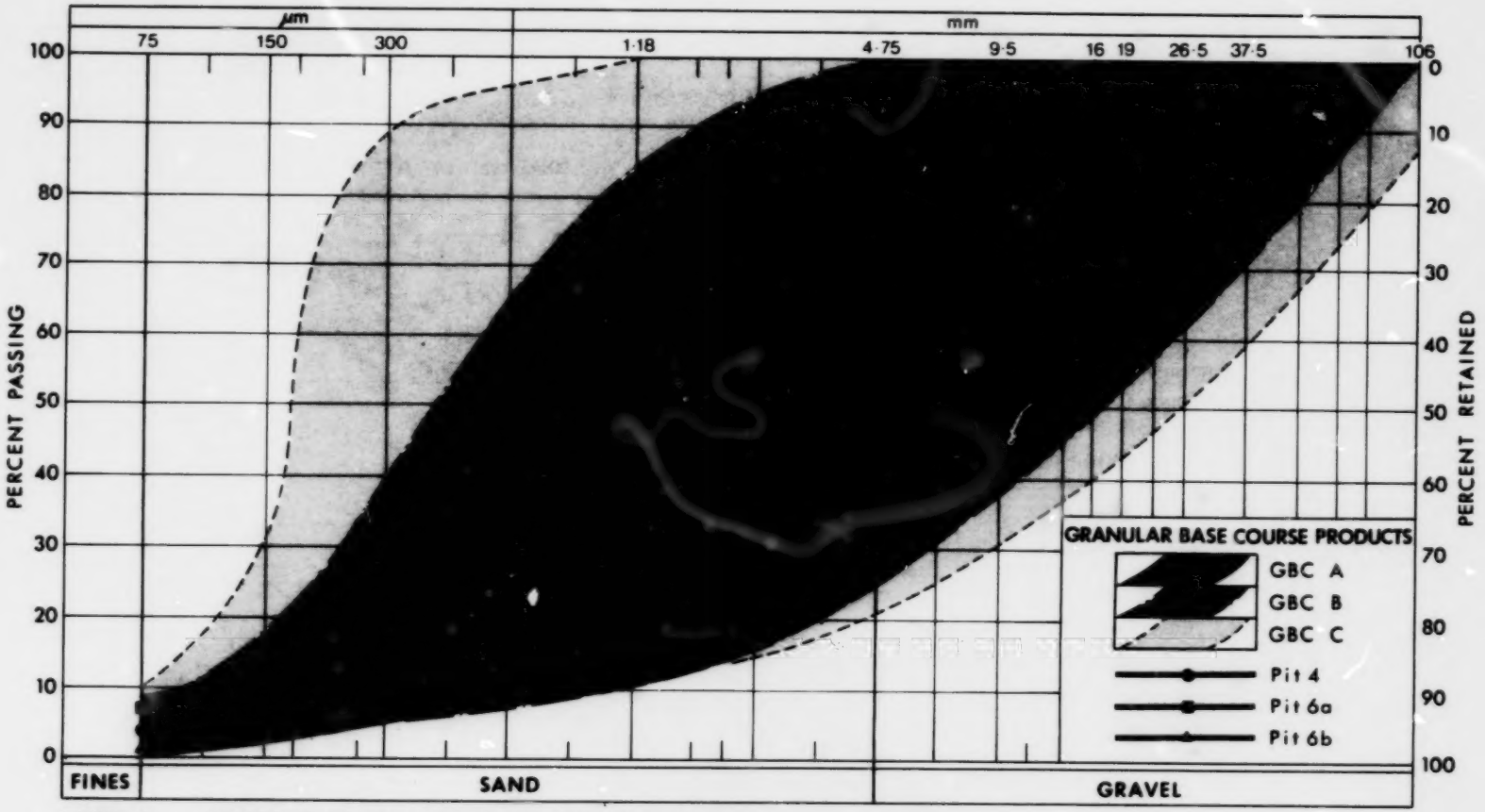


FIGURE 3a. AGGREGATE GRADING CURVES, COLLINGWOOD TOWNSHIP.

Based on analysis of the total aggregate contained in unprocessed samples (gradation envelopes adapted from M.T.O. Form 1010, 1980).

NOTE: Information portrayed by grading curves refers strictly to a specific sample taken at the time of field investigation. Due to the inherent variability of sand and gravel deposits care should be exercised in extrapolating such information to the rest of the deposit.

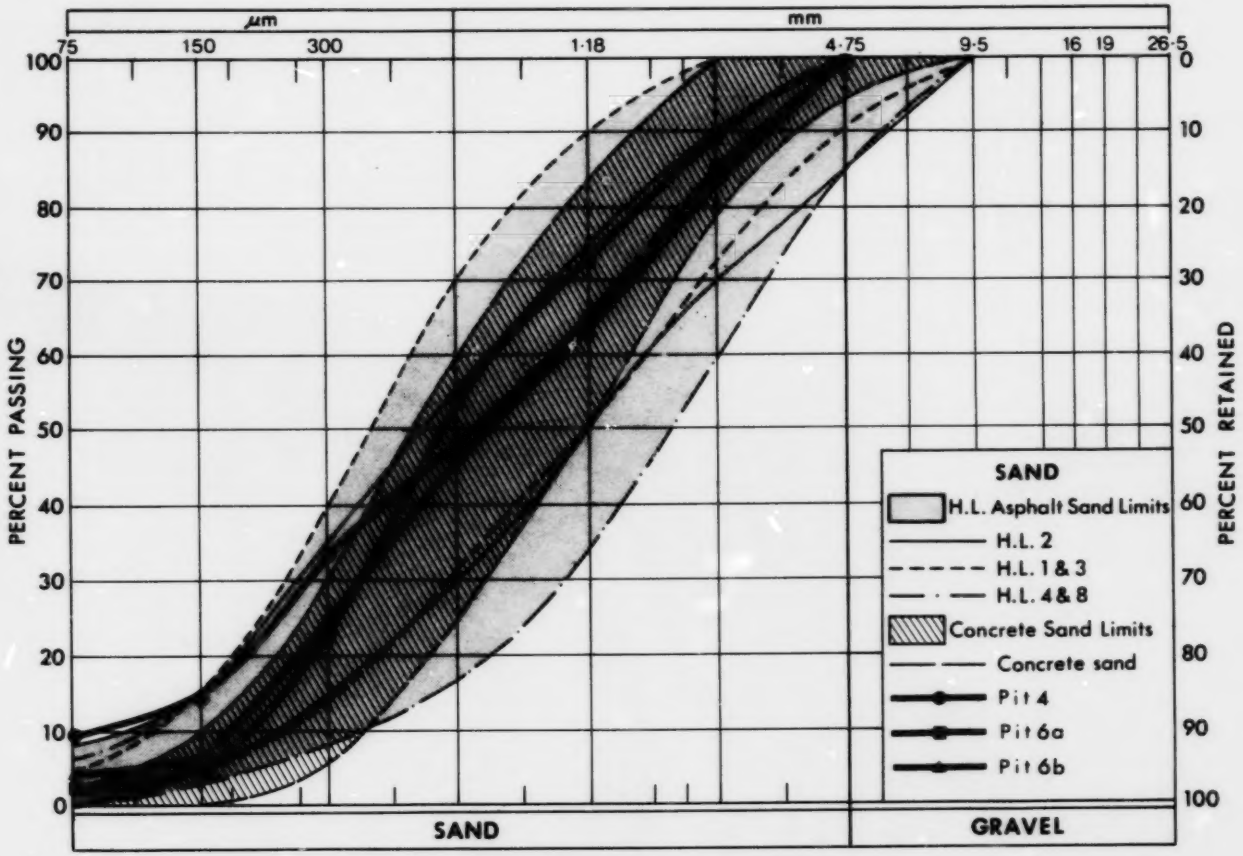


FIGURE 3b. AGGREGATE GRADING CURVES, COLLINGWOOD TOWNSHIP.

Based on analysis of the sand fraction of the aggregate contained in unprocessed samples (gradation envelopes adapted from M.T.O. Forms 1002, 1979 and 1003, 1981).

NOTE:

Information portrayed by grading curves refers strictly to a specific sample taken at the time of field investigation. Due to the inherent variability of sand and gravel deposits care should be exercised in extrapolating such information to the rest of the deposit.

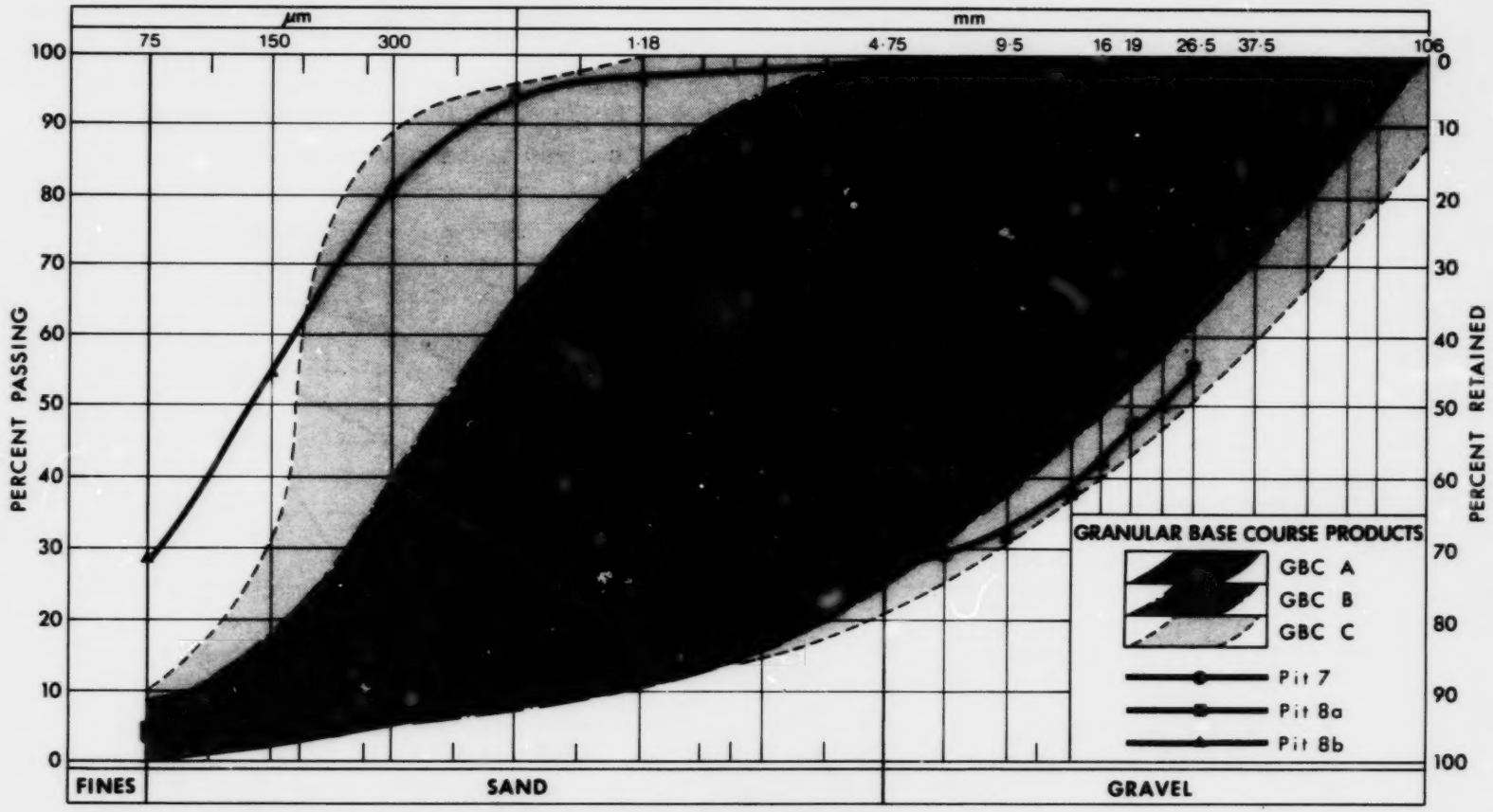


FIGURE 4a. AGGREGATE GRADING CURVES, COLLINGWOOD TOWNSHIP.

Based on analysis of the total aggregate contained in unprocessed samples (gradation envelopes adapted from M.T.O. Form 1010, 1980).

NOTE: Information portrayed by grading curves refers strictly to a specific sample taken at the time of field investigation. Due to the inherent variability of sand and gravel deposits care should be exercised in extrapolating such information to the rest of the deposit.

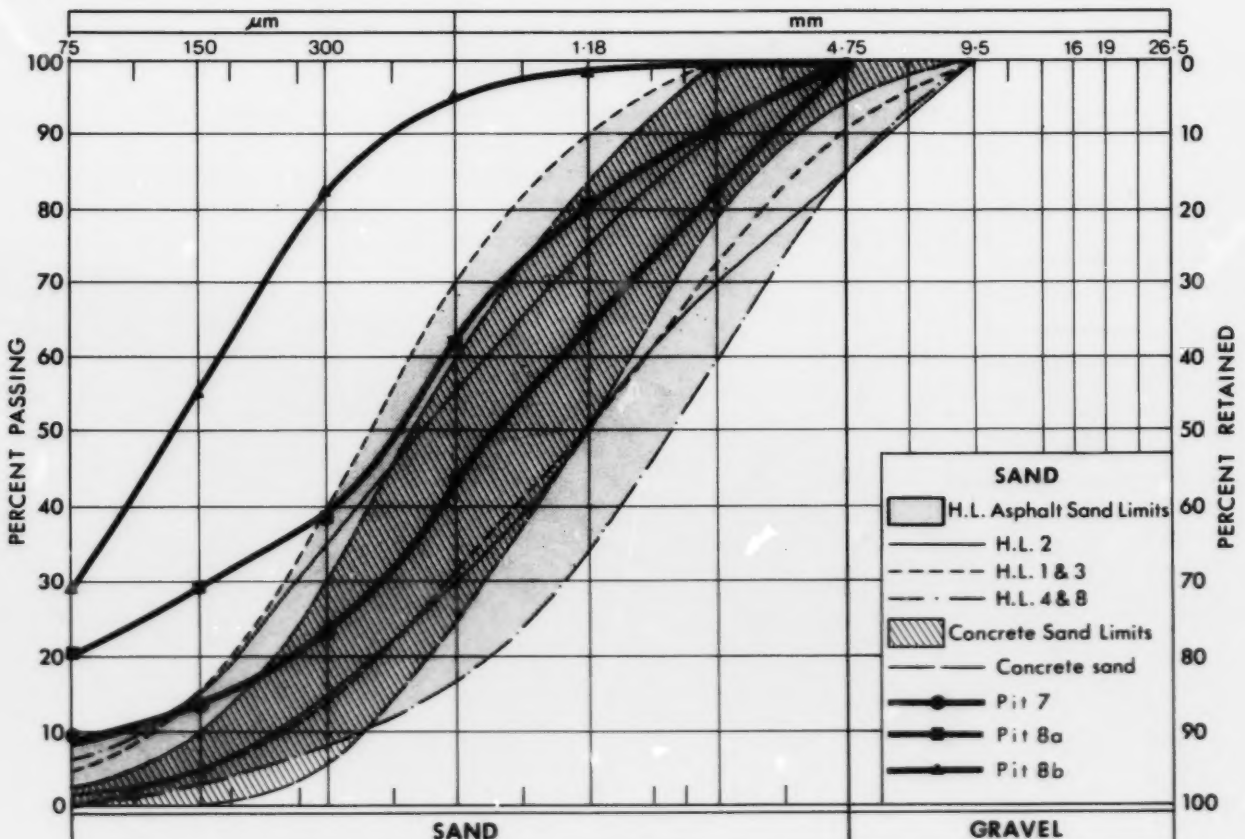


FIGURE 4b. AGGREGATE GRADING CURVES, COLLINGWOOD TOWNSHIP.

Based on analysis of the sand fraction of the aggregate contained in unprocessed samples (gradation envelopes adapted from M.T.O. Forms 1002, 1979 and 1003, 1981).

NOTE:

Information portrayed by grading curves refers strictly to a specific sample taken at the time of field investigation. Due to the inherent variability of sand and gravel deposits care should be exercised in extrapolating such information to the rest of the deposit.

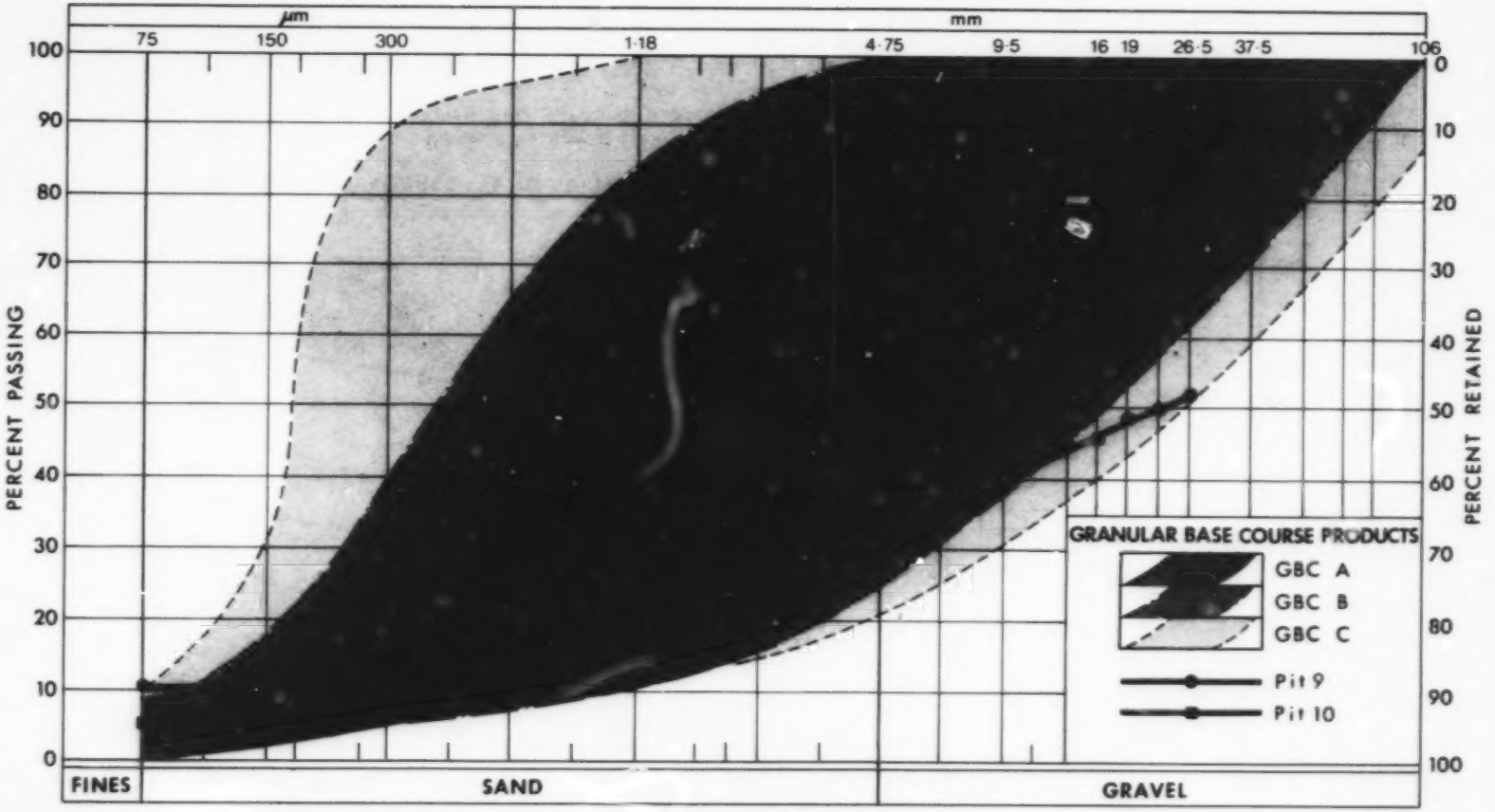


FIGURE 5a. AGGREGATE GRADING CURVES, COLLINGWOOD TOWNSHIP.

Based on analysis of the total aggregate contained in unprocessed samples (gradation envelopes adapted from M.T.O. Form 1010, 1980).

NOTE: Information portrayed by grading curves refers strictly to a specific sample taken at the time of field investigation. Due to the inherent variability of sand and gravel deposits care should be exercised in extrapolating such information to the rest of the deposit.

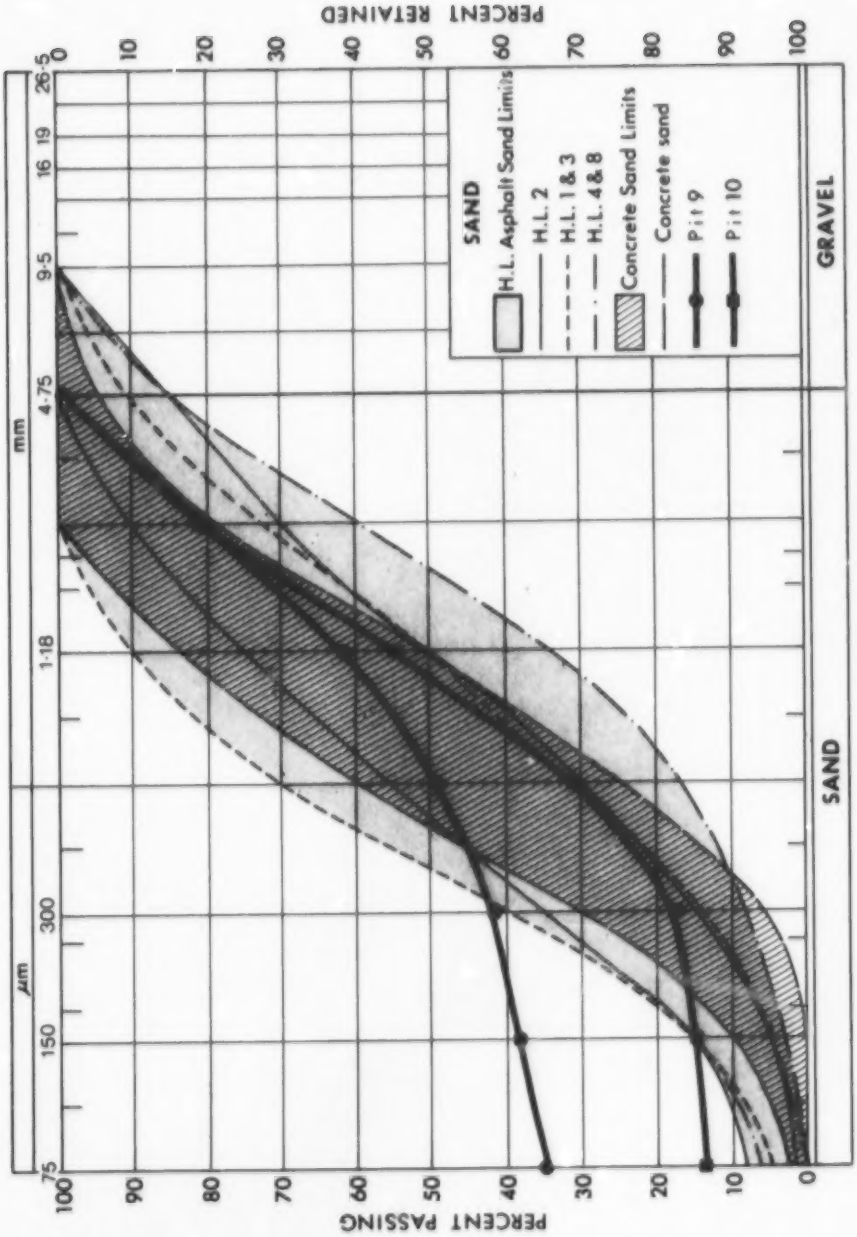


FIGURE 5b. AGGREGATE GRADING CURVES, COLLINGWOOD TOWNSHIP.

Based on analysis of the sand fraction of the aggregate contained in unprocessed samples (gradation envelopes adapted from M.T.O. Forms 1002, 1979 and 1003, 1981).

NOTE:

Information portrayed by grading curves refers strictly to a specific sample taken at the time of field investigation. Due to the inherent variability of sand and gravel deposits care should be exercised in extrapolating such information to the rest of the deposit.

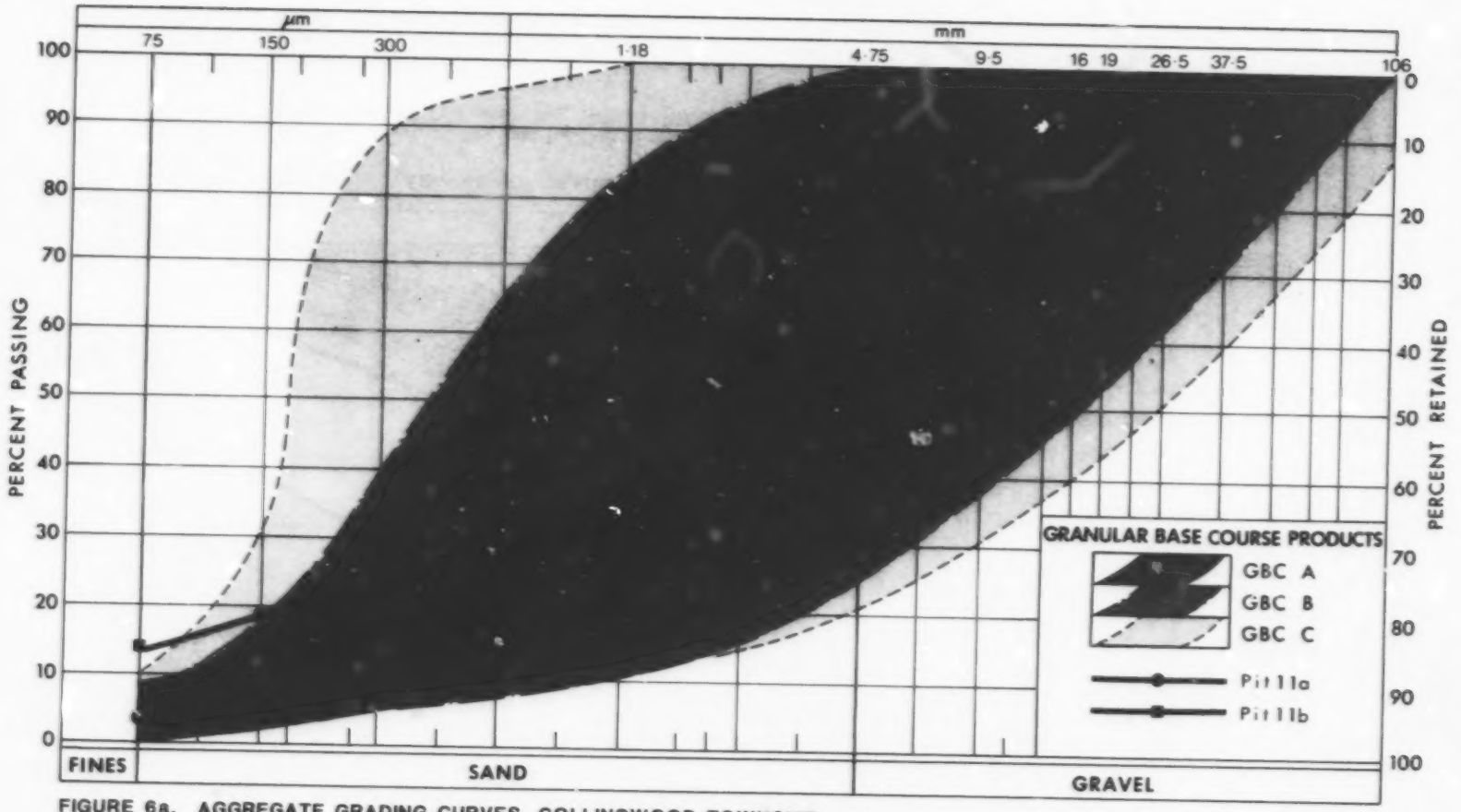


FIGURE 6a. AGGREGATE GRADING CURVES, COLLINGWOOD TOWNSHIP

Based on analysis of the total aggregate contained in unprocessed samples (gradation envelopes adapted from M.T.O. Form 1010, 1980).

NOTE: Information portrayed by grading curves refers strictly to a specific sample taken at the time of field investigation. Due to the inherent variability of sand and gravel deposits care should be exercised in extrapolating such information to the rest of the deposit.

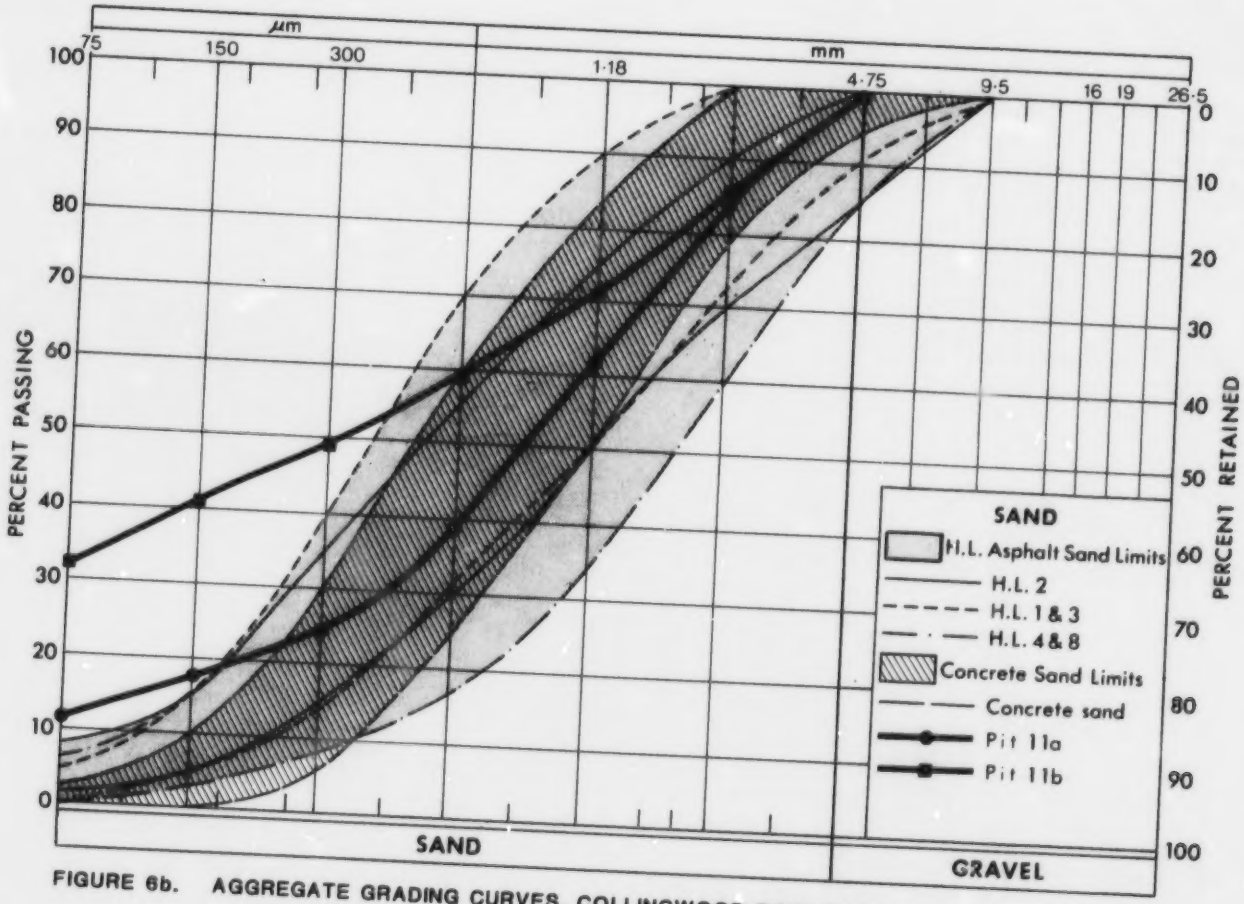


FIGURE 6b. AGGREGATE GRADING CURVES, COLLINGWOOD TOWNSHIP.

Based on analysis of the sand fraction of the aggregate contained in unprocessed samples (gradation envelopes adapted from M.T.O. Forms 1002, 1979 and 1003, 1981).

NOTE:

Information portrayed by grading curves refers strictly to a specific sample taken at the time of field investigation. Due to the inherent variability of sand and gravel deposits care should be exercised in extrapolating such information to the rest of the deposit.

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Appendix A — Suggested Additional Reading

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Appendix B — Glossary

Abrasion resistance: Tests such as the Los Angeles abrasion test are used to measure the ability of aggregate to resist crushing and pulverizing under conditions similar to those encountered in processing and use. Measuring resistance is an important component in the evaluation of the quality and prospective uses of aggregate. Hard, durable material is preferred for road building.

Absorption capacity: Related to the porosity of the rock types of which an aggregate is composed. Porous rocks are subject to disintegration when absorbed liquids freeze and thaw, thus decreasing the strength of the aggregate.

Aggregate: Any hard, inert, construction material (sand, gravel, shells, slag, crushed stone or other mineral material) used for mixing in various-sized fragments with a cement or bituminous material to form concrete, mortar, etc., or used alone for road building or other construction. Synonyms include mineral aggregate and granular material.

Aggregate Abrasion Value: This test directly measures the resistance of aggregate to abrasion with silica sand and a steel disk. The higher the value, the lower the resistance to abrasion. For high quality asphalt surface course uses, values of less than 6 are desireable.

Alkali-aggregate reaction: A chemical reaction between the alkalis of portland cement and certain minerals found in rocks used for aggregate. Alkali-aggregate reactions are undesirable because they can cause expansion and cracking of concrete. Although perfectly suitable for building stone and asphalt applications, alkali-reactive aggregates should be avoided for structural concrete uses.

Beneficiation: Beneficiation of aggregates is a process or combination of processes which improves the quality (physical properties) of a mineral aggregate and is not part of the normal processing for a particular use, such as routine crushing, screening, washing or classification. Heavy media separation, jigging, or application of special crushers (e.g., "cage mill") are usually considered processes of beneficiation.

Blending: Required in cases of extreme coarseness, fineness, or other irregularities in the gradation of unprocessed aggregate. Blending is done with approved sand-sized aggregate in order to satisfy the gradation requirements of the material.

Bulk Relative Density: An aggregate with low relative density is lighter in weight than one with a high relative density. Low relative density aggregates (less than about 2.5) are often non-durable for many aggregate uses.

Cambrian: The first period of the Paleozoic Era, thought to have covered the time between 570 and 500 million years ago. The Cambrian precedes the Ordovician Period.

Clast: An individual constituent, grain or fragment of a sediment or rock, produced by the mechanical weathering of larger rock mass. Synonyms include particle and fragment.

Crushable aggregate: Unprocessed gravel containing a minimum of 35% coarse aggregate larger than the No. 4 sieve (4.75 mm) as well as a minimum of 20% greater than the 6.5 mm sieve.

Deleterious lithology: A general term used to designate those rock types which are chemically or physically unsuited for use as construction or road-building aggregates. Such lithologies as chert, shale, siltstone and sandstone may deteriorate rapidly when exposed to traffic and other environmental conditions.

Devonian: A period of the Paleozoic Era thought to have covered the span of time between 395 and 345 million years ago, following the Silurian Period. Rocks formed in the Devonian Period are among the youngest found in Ontario.

Dolostone: A carbonate sedimentary rock consisting chiefly of the mineral dolomite and containing relatively little calcite (dolostone is also known as dolomite).

Drift: A general term for all unconsolidated rock debris transported from one place and deposited in another, distinguished from underlying bedrock. In North America, glacial activity has been the dominant mode of transport and deposition of drift. Synonyms include overburden and surficial deposit.

Drumlin: A low, smoothly rounded, elongated hill, mound, or ridge composed of glacial materials. These landforms were formed beneath an advancing ice sheet, and were shaped by its flow.

Eolian: Pertaining to the wind, especially with respect to landforms whose constituents were transported and deposited by wind activity. Sand dunes are an example of an eolian landform.

Fines: A general term used to describe the size fraction of an aggregate which passes (is finer than) the No. 200 mesh screen (0.075 mm). Also described informally as "dirt", these particles are in the silt and clay size range.

Glacial lobe: A tongue-like projection from the margin of the main mass of an ice cap or ice sheet. During the Pleistocene Epoch several lobes of the Laurentide continental ice sheet occupied the Great Lakes basins. These lobes advanced then melted back numerous times during the Pleistocene, producing the complex arrangement of glacial material and landforms found in southern Ontario.

Gradation: The proportion of material of each particle size, or the frequency distribution of the various sizes which constitute a sediment. The strength, durability, permeability and stability of an aggregate depend to a great extent on its gradation. The size limits for different particles are as follows:

Boulder	more than 200 mm
Cobbles	75-200 mm
Coarse Gravel	26.5-75 mm
Fine Gravel	4.75-26.5 mm
Coarse Sand	2-4.75 mm
Medium Sand	0.425-2 mm
Fine Sand	0.075-0.425 mm
Silt, Clay	less than 0.075 mm

Granular base course: Components of the pavement structure of a road, which are placed on the subgrade and are designed to provide strength, stability and drainage, as well as support for surfacing materials. Several types have been defined: Granular Base Course A consists of crushed and processed aggregate and has relatively stringent quality standards in comparison to Granular Base Course B and C which are usually pit-run or other unprocessed aggregate.

Hot-laid (or asphaltic) aggregate: Bituminous, cemented aggregates used in the construction of pavements either as surface or bearing course (HL 1, 3 and 4), or as binder course (HL 2 and 8) used to bind the surface course to the underlying granular base course.

Lithology: The description of rocks on the basis of such characteristics as colour, structure, mineralogic composition and grain size. Generally, the description of the physical character of a rock.

Los Angeles Abrasion and Impact Test: This test measures the resistance to abrasion and the impact strength of aggregate. This gives an idea of the breakdown that can be expected to occur when an aggregate is stockpiled, transported, and placed. Values less than about 35% indicate potentially satisfactory performance for most concrete and aspphalt uses. Values of more than 45% indicate that the aggregate may be susceptible to excessive breakdown during handling and placing.

Magnesium sulphate soundness test: This test is designed to simulate the action of freezing and thawing on aggregates. Those aggregates which are susceptible to freezing and thawing will usually break down and give high losses in this test. Values greater than about 12 to 15% indicate potential problems for concrete and asphalt coarse aggregate.

Meltwater channel: A drainage way, often terraced, produced by water flowing away from a melting glacier margin.

Ordovician: An early period of the Paleozoic Era thought to have covered the span of time between 500 and 435 million years ago.

Paleozoic era: One of the major divisions of the geologic time scale thought to have covered the time between 570 and 230 million years ago, the Paleozoic Era (or Ancient Life Era) is subdivided into six geologic periods, of which only four (Cambrian, Ordovician, Silurian and Devonian) can be recognized in southern Ontario.

Petrographic examination: Individual aggregate particles in a sample are divided into categories good, fair, poor, and deleterious, based on their rock type (petrography) and knowledge of past field performance. A petrographic number (PN) is calculated. The higher the PN, the lower the quality of the aggregate.

Pleistocene: An epoch of the recent geological past including the time from approximately 2 million years ago to 7000 years ago. Much of the Pleistocene was characterized by extensive glacial activity and is popularly referred to as the "Great Ice Age".

Polished Stone Value: This test measures the frictional properties of aggregates after 6 hours of abrasion and polishing with an emery abasive. The higher the PSV, the higher the frictional properties of the aggregate. Values less than 45 indicate marginal frictional properties, while values greater than 55 indicate excellent frictional properties.

Possible resource: Reserve estimates based largely on broad knowledge of the geological character of the deposit and for which there are few, if any, samples or measurements. The estimates are based on assumed continuity or repetition for which there are reasonable geological indications.

Precambrian: The earliest geological period extending from the consolidation of the earth's crust to the beginning of the Cambrian.

Shale: A fine-grained sedimentary rock formed by the consolidation of clay, silt or mud and characterized by well developed bedding planes, along which the rock breaks readily into thin layers. The term shale is also commonly used for fissile claystone, siltstone and mudstone.

Silurian: An early period of the Palezoic Era thought to have covered the time between 435 and 395 million years ago. The Silurian follows the Ordovician Period and precedes the Devonian Period.

Soundness: The ability of the components of an aggregate to withstand the effects of various weathering processes and agents. Unsound lithologies are subject to disintegration caused by the expansion of absorbed solutions. This may seriously impair the performance of road-building and construction aggregates.

Till: Unsorted and unstratified rock debris, deposited directly by glaciers, and ranging in size from clay to large boulders.

Wisconsinan: Pertaining to the last glacial period of the Pleistocene Epoch in North America. The Wisconsinan began approximately 100 000 years ago and ended approximately 7000 years ago. The glacial deposits and landforms of southern Ontario are predominantly the result of glacial activity during the Wisconsinan Stage.

Appendix C — Geology of Sand and Gravel Deposits

The type, distribution, and extent of sand and gravel deposits in southern Ontario are the result of extensive glacial and glacially influenced activity in Wisconsinan time during the Pleistocene Epoch, approximately 100 000 to 7000 years ago. The deposit types reflect the different depositional environments that existed during the melting and retreat of the continental ice masses, and can readily be differentiated on the basis of their morphology, structure, and texture. The deposit types are described below.

GLACIOFLUVIAL DEPOSITS

These deposits can be divided into two broad categories: those that were formed in contact with (or in close proximity to) glacial ice, and those that were deposited by meltwaters carrying materials beyond the ice margin.

Ice-Contact Terraces (ICT): These are glaciofluvial features deposited between the glacial margin and a confining topographic high, such as the side of a valley. The structure of the deposits may be similar to that of outwash deposits, but in most cases the sorting and grading of the material is more variable and the bedding is discontinuous because of extensive slumping. The probability of locating large amounts of crushable aggregate is moderate, and extraction may be expensive because of the variability of the deposits both in terms of quality and grain size distribution.

Kames (K): Kames are defined as mounds of poorly sorted sand and gravel deposited by meltwater in depressions or fissures on the ice surface or at its margin. During glacial retreat, the melting of supporting ice causes collapse of the deposits, producing internal structures characterized by bedding discontinuities. The deposits consist mainly of irregularly bedded and cross-bedded, poorly sorted sand and gravel. The present forms of the deposits include single mounds, linear ridges (crevasse fillings) or complex groups of landforms. The latter are occasionally described as "undifferentiated ice-contact stratified drift" (IC) when detailed subsurface information is unavailable. Since kames commonly contain large amounts of fine-grained material and are characterized by considerable variability, there is generally a low to moderate probability of discovering large amounts of good quality, crushable aggregate. Extractive problems encountered in these deposits are mainly the excessive variability of the aggregate and the rare presence of excess fines (silt- and clay-sized particles).

Eskers (E): Eskers are narrow, sinuous ridges of sand and gravel deposited by meltwaters flowing in tunnels within or at the base of glaciers, or in channels on the ice surface. Eskers vary greatly in size. Many, though not all eskers, consist of a central core of poorly sorted and stratified gravel characterized by a wide range in grain size. The core material is often draped on its flanks by better sorted and stratified gravel. The deposits have a high probability of containing a large proportion of crushable aggregate, and since they are generally built above the surrounding ground surface, are convenient extraction sites. For these reasons esker deposits have been traditional aggregate sources throughout Ontario, and are significant components of the total resources of many areas.

Some planning constraints and opportunities are inherent in the nature of the deposits. Because of their linear nature, the deposits commonly extend across several property boundaries leading to unorganized extractive development at numerous small pits. On the other hand, because of their form, eskers can be easily and inexpensively extracted and are amenable to rehabilitation and sequential land use.

Undifferentiated Ice-Contact Stratified Drift (IC): This designation may include deposits from several ice-contact, depositional environments which usually form extensive, complex landforms. It is not feasible to identify individual areas of coarse-grained material within such deposits because of their lack of continuity and grain size variability. They are given a qualitative rating based on existing pit and other subsurface data.

Outwash (OW): Outwash deposits consist of sand and gravel laid down by meltwaters beyond the margin of the ice lobes. The deposits occur as sheets or as terraced valley fills (valley trains) and may be very large in extent and thickness. Well developed outwash deposits have good horizontal bedding and are uniform in grain size distribution. Outwash deposited near the glacier's margin is much more variable in texture and structure. The probability of locating useful crushable aggregates in outwash deposits is moderate to high depending on how much information on size, distribution and thickness is available.

Subaqueous Fan (SF): Subaqueous fans are formed within or near the mouths of meltwater conduits when sediment laden meltwaters are discharged into a standing body of water. The geometry of the resulting deposit is fan or lobe shaped. Several of these lobes may be joined together to form a larger, continuous sedimentary body. Internally, subaqueous fans consist of stratified sands and gravels which may exhibit wide variations in grain size distribution. As these features were deposited under glacial lake waters, silt and clay which settled out of these lakes may be associated in varying amounts with these deposits. The variability of the sediments and presence of fines are the main extractive problems associated with these deposits.

Alluvium (AL): Alluvium is a general term for clay, silt, sand, gravel, or similar unconsolidated material deposited during postglacial time by a stream as sorted or semi-sorted sediment, on its bed or on its floodplain. The probability of locating large amounts of crushable aggregate in alluvial deposits is low, and they have gen-

erally low value because of the presence of excess silt- and clay-sized material. There are few large postglacial alluvium deposits in Ontario.

GLACIOLACUSTRINE DEPOSITS

Glaciolacustrine Beach Deposits (LB): These are relatively narrow, linear features formed by wave action at the shores of glacial lakes that existed at various times during the deglaciation of southern Ontario. Well developed lacustrine beaches are usually less than 20 feet (6 m) thick. The aggregate is well sorted and stratified and sand-sized material commonly predominates. The composition and size distribution of the deposit depends on the nature of the source material. The probability of obtaining crushable aggregate is high when the material is developed from coarse-grained materials such as a stony till, and low when developed from fine-grained materials. Beaches are relatively narrow, linear deposits, so that extractive operations are often numerous and extensive.

Glaciolacustrine Deltas (LD): These features were formed where streams or rivers of glacial meltwater flowed into lakes and deposited their suspended sediment. In southern Ontario such deposits tend to consist mainly of sand and abundant silt. However, in near-ice and ice-contact positions, coarse material may be present. Although deltaic deposits may be large, the probability of obtaining coarse material is generally low.

Glaciolacustrine Plains (LP): The nearly level surface marking the floor of an extinct glacial lake. The sediments which form the plain are predominantly fine to medium sand, silt, and clay, and were deposited in relatively deep water. Lacustrine deposits are generally of low value as aggregate sources because of their fine grain size and lack of crushable material. In some aggregate-poor areas, lacustrine deposits may constitute valuable sources of fill and some granular base course aggregate.

GLACIAL DEPOSITS

End Moraines (EM): These are belts of glacial drift deposited at, and parallel to, glacier margins. End moraines commonly consist of ice-contact stratified drift and in such instances are usually called kame moraines. Kame moraines commonly result from deposition between two glacial lobes (interlobate moraines). The probability of locating aggregates within such features is moderate to low. Exploration and development costs are high. Moraines may be very large and contain vast aggregate resources, but the location of the best areas within the moraine is usually poorly defined.

EOLIAN DEPOSITS

Windblown Deposits (WD): Windblown deposits are those formed by the transport and deposition of sand by winds. The form of the deposits ranges from extensive, thin layers to well developed linear and crescentic ridges known as dunes. Most windblown deposits in southern Ontario are derived from, and deposited on, pre-existing lacustrine sand plain deposits. Windblown sediments almost always consist of fine to coarse sand and are usually well sorted. The probabiltiy of locating crushable aggregate in windblown deposits is very low.

Appendix D — Geology of Bedrock Deposits

The purpose of this appendix is to familiarize the reader with the general bedrock geology of southern Ontario (Figure D1), and the potential uses of the various bedrock formations where known. The reader is cautioned against using this information for more specific purposes. The stratigraphic chart (Figure D2) is intended only to illustrate the stratigraphic sequences in particular geographic areas and should not be used as a regional correlation table.

The following description is arranged in ascending stratigraphic order, on a group and formation basis. Precambrian rocks are not discussed. Additional stratigraphic information is included for some formations where necessary. The publications and maps of the Ontario Geological Survey and the Geological Survey of Canada should be referred to for more detailed information. The composition, thickness, and uses of the formations are discussed. If a formation may be suitable for use as aggregate and aggregate suitability test data is available, the data has been included in the form of ranges. The following short forms have been used in presenting this data: PSV = Polished Stone Value, AAV = Aggregate Abrasion Value, $MgSO_4$ = Magnesium Sulphate Soundness Test (loss in percent), LA = Los Angeles Abrasion and Impact Test (loss in percent), Absn = Absorption (percent), BRD = Bulk Relative Density, PN (Asphalt & Concrete) = Petrographic Number for Asphalt and Concrete use.

The ranges are intended as a guide only and care should be exercised in extrapolating the information to specific situations. Aggregate suitability test data has been provided by the Ontario Ministry of Transportation.

Covey Hill Formation (Cambrian)

STRATIGRAPHY: lower formation of the Potsdam Group. COMPOSITION: interbedded non-calcareous feldspathic conglomerate and sandstone. THICKNESS: 0 to 45 feet (0 to 14 m). USES: has been quarried for aggregate in South Burgess Township, Leeds County.

Nepean Formation (Cambro-Ordovician)

STRATIGRAPHY: upper formation of the Potsdam Group. COMPOSITION: thin-bedded to massive quartz sandstone with some conglomerate interbeds and rare shaly partings. THICKNESS: 0 to 100 feet (0 to 30 m). USES: suitable as dimension stone; quarried at Philipsville and Forfar for silica sand; alkali-silica reactive in Portland cement concrete. AGGREGATE SUITABILITY TESTING: PSV = 54-68, AAV = 4-15, $MgSO_4$ = 9-32, LA = 44-90, Absn = 1.6-2.6, BRD = 2.38-2.50, PN (Asphalt & Concrete) = 130-140.

March Formation (Lower Ordovician)

STRATIGRAPHY: lower formation of the Beekmantown Group. COMPOSITION: interbedded quartz sandstone, dolomitic quartz sandstone, sandy dolostone and dolostone. THICKNESS: 60 to 197 feet (18 to 60 m). USES: quarried extensively for aggregate in area of subcrop and outcrop; alkali-silica reactive in Portland cement concrete; lower part of formation is an excellent source of skid-resistant aggregate. Suitable for use as facing stone and paving stone. AGGREGATE SUITABILITY TESTING: PSV = 55-60, AAV = 4-6, $MgSO_4$ = 1-17, LA = 15-38, Absn = 0.5-0.9, BRD = 2.61-2.65, PN (Asphalt & Concrete) = 110-150.

Oxford Formation (Lower Ordovician)

STRATIGRAPHY: upper formation of the Beekmantown Group. COMPOSITION: thin- to thick-bedded, microcrystalline to medium-crystalline, grey dolostone with thin shaly interbeds. THICKNESS: 200 to 335 feet (61 to 102 m). USES: quarried in the Brockville and Smith Falls areas and south of Ottawa for use as aggregate. AGGREGATE SUITABILITY TESTING: PSV = 47-48, AAV = 7-8, $MgSO_4$ = 1-4, LA = 18-23, Absn = 0.7-0.9, BRD = 2.74-2.78, PN (Asphalt & Concrete) = 105-120.

Rockcliffe Formation (Middle Ordovician)

STRATIGRAPHY: divided into lower member and upper (St. Martin) member. COMPOSITION: interbedded quartz sandstone and shale; interbedded shaly bioclastic limestone and shale predominating in upper member to the east. THICKNESS: 0 to 410 feet (0 to 125 m). USES: upper member has been quarried east of Ottawa for aggregate; lower member has been used as crushed stone; some high purity limestone beds in upper member may be suitable for use as fluxing stone and in lime production. AGGREGATE SUITABILITY TESTING: PSV = 58-63, AAV = 10-11, $MgSO_4$ = 12-40, LA = 25-28, Absn = 1.8-1.9, BRD = 2.55-2.62, PN (Asphalt & Concrete) = 122-440.

Shadow Lake Formation (Middle Ordovician)

STRATIGRAPHY: eastern Ontario - the basal unit of the Ottawa Group; central Ontario - overlain by the Simcoe Group. COMPOSITION: in eastern Ontario - silty and sandy dolostone with shale partings and minor interbeds of sandstone; in central Ontario - conglomer-

ates, sandstones, and shales. THICKNESS: eastern Ontario - 7 to 10 feet (2 to 3 m); central Ontario - 0 to 40 feet (0 to 12 m). USES: potential source of decorative stone; very limited value as aggregate source.

Gull River Formation (Middle Ordovician)

STRATIGRAPHY: part of the Simcoe Group (central Ontario) and Ottawa Group (eastern Ontario). In central and eastern Ontario the formation is subdivided into upper and lower members; west of Lake Simcoe it is presently subdivided into upper, middle and lower members. COMPOSITION: in central and eastern Ontario the lower member consists of alternating units of limestone, dolomitic limestone, and dolostone, the upper member consists of thin-bedded limestones with thin shale partings; west of Lake Simcoe the lower member is thin- to thick-bedded, interbedded, grey argillaceous limestone and buff to green dolostone whereas the upper and middle members are dense microcrystalline limestones with argillaceous dolostone interbeds. THICKNESS: 23 to 204 feet (7 to 62 m). USES: Quarried in the Lake Simcoe, Kingston, Ottawa, and Cornwall areas for crushed stone. Rock from certain layers in eastern and central Ontario has proven to be alkali-reactive when used in Portland cement concrete (alkali-carbonate reaction). AGGREGATE SUITABILITY TESTING: PSV = 41-49, AAV = 8-12, $MgSO_4$ = 3-13, LA = 18-28, Absn = 0.3-0.9, BRD = 2.68-2.73, PN (Asphalt & Concrete) = 100-153.

Bobcaygeon Formation (Middle Ordovician)

STRATIGRAPHY: part of the Simcoe Group (central Ontario) and the Ottawa Group (eastern Ontario), subdivided into upper, middle and lower members; members in eastern and central Ontario are approximately equivalent. COMPOSITION: homogeneous, massive to thin-bedded fine-crystalline limestone with numerous shaly partings in the middle member. THICKNESS: 80 to 285 feet (24 to 87 m). USES: Quarried at Brechin, Marysville, and in the Ottawa area for crushed stone. Generally suitable for use as granular base course aggregate. Rock from certain layers has been found to be alkali-reactive when used in Portland cement concrete (alkali-silica reaction). AGGREGATE SUITABILITY TESTING: PSV = 47-51, AAV = 14-23, $MgSO_4$ = 1-40, LA = 18-32, Absn = 0.3-2.4, BRD = 2.5-2.69, PN (Asphalt & Concrete) = 100-320.

Verulam Formation (Middle Ordovician)

STRATIGRAPHY: part of Simcoe and Ottawa Groups. COMPOSITION: fossiliferous, pure to argillaceous limestone interbedded with calcareous shale. THICKNESS: 105 to 230 feet (32 to 70 m). USES: Quarried at Picton and Bath for use in cement manufacture. Quarried for aggregate in Mara Township, Simcoe County and in the Belleville-Kingston area. May be unsuitable for use as aggregate in some areas because of its high shale content. AGGREGATE SUITABILITY TESTING: PSV = 43-44, AAV = 9-13, $MgSO_4$ = 4-45, LA = 22-29, Absn = 0.4-2.1, BRD = 2.59-2.70, PN (Asphalt & Concrete) = 120-255.

Lindsay Formation (Middle and Upper Ordovician)

STRATIGRAPHY: part of Simcoe and Ottawa Groups; in eastern Ontario is divisible into an unnamed lower member and the Eastview Member; in central Ontario is divisible into the Collingwood Member (equivalent to portions of the Eastview Member) and a lower member. COMPOSITION: eastern Ontario - the lower member is interbedded, very fine- to coarse-crystalline limestone with undulating shale partings and interbeds of dark grey calcareous shale, whereas the Eastview Member is an interbedded dark grey to dark brown calcareous shale and very fine- to fine-crystalline, petroliferous limestone; central Ontario - Collingwood Member is a black, calcareous shale whereas the lower member is a very fine- to coarse-crystalline, thin-bedded limestone with very thin, undulating shale partings. THICKNESS: 82 to 200 feet (25 to 61 m). USES: eastern Ontario - lower member is used extensively for aggregate production; central Ontario - quarried at Picton, Ogden Point and Bowmanville for cement. May be suitable or unsuitable for use as concrete and asphalt aggregate. AGGREGATE SUITABILITY TESTING: $MgSO_4$ = 2-47, LA = 20-28, Absn = 0.4-1.3, BRD = 2.64-2.70, PN (Asphalt & Concrete) = 110-215.

Blue Mountain and Billings Formations (Upper Ordovician)

STRATIGRAPHY: central Ontario - Blue Mountain Formation includes the upper and middle members of the former Whitby Formation; eastern Ontario - Billings Formation is equivalent to part of the Blue Mountain Formation. COMPOSITION: Blue Mountain Formation blue-grey, noncalcareous shales; Billings Formation - dark grey to black, noncalcareous to slightly calcareous, pyritiferous shale with dark grey limestone laminae and grey siltstone interbeds. THICKNESS: Blue Mountain Formation - 140 to 200 feet (43 to 61 m); Billings Formation - 0 to 205 feet (0 to 62 m). USES: Billings Formation may be a suitable source for structural clay products and expanded aggregate; Blue Mountain Formation may be suitable for structural clay products.

Georgian Bay and Carlsbad Formations (Upper Ordovician)

COMPOSITION: central Ontario - Georgian Bay Formation composed of interbedded limestone and shale; eastern Ontario - Carlsbad Formation composed of interbedded shale, siltstone and bioclastic limestone; THICKNESS: Georgian Bay Formation - 300 to 560 feet (91 to 170 m); Carlsbad Formation - 0 to 610 feet (0 to 186 m). USES: Georgian Bay Formation - used by several producers in Metropolitan Toronto area to produce

brick and structural tile, as well as for making Portland cement; at Streetsville, expanded shale was used in the past to produce lightweight aggregate. Carlsbad Formation - used as a source material for brick and tile manufacturing, has potential as a lightweight expanded aggregate.

Queenston Formation (Upper Ordovician)

COMPOSITION: red, thin- to thick-bedded, sandy to argillaceous shale with green mottling and banding. THICKNESS: 400 to 500 feet (122 to 152 m). USES: There are several large quarries developed in the Queenston Formation in the Toronto-Hamilton region and one at Russell, near Ottawa. All extract shale for brick manufacturing. The Queenston Formation is the most important source material for brick manufacture in Ontario.

Whirlpool Formation (Lower Silurian)

STRATIGRAPHY: lower formation in the Cataract Group in the Niagara Penninsula and the Niagara Escarpment as far north as Duntroon. COMPOSITION: massive, medium- to coarse-grained, argillaceous white to light grey quartz sandstone with thin grey shale partings. THICKNESS: 0 to 25 feet (0 - 8 m). USES: building stone, flagstone.

Manitoulin Formation (Lower Silurian)

STRATIGRAPHY: part of the Cataract Group, occurs north of Stoney Creek. COMPOSITION: thin-bedded, blue-grey to buff-brown dolomitic limestones and dolostones. THICKNESS: 0 to 75 feet (0 to 23 m). USES: extracted for crushed stone in St. Vincent Township, Grey County, and for decorative stone on Manitoulin Island. AGGREGATE SUITABILITY TESTING: No data.

Cabot Head Formation (Lower Silurian)

STRATIGRAPHY: part of the Cataract Group, occurs throughout southern Ontario, south and north of the Niagara Escarpment. COMPOSITION: green, grey and red shales. THICKNESS: 50 to 60 feet (15 to 18 m); USES: potential source of coated lightweight aggregate and raw material for use in manufacture of brick and tile. Lack of suitability exposures has limited use.

Grimsby Formation

STRATIGRAPHY: upper formation of the Cataract Group, is identified on the Niagara Peninsula as far north as Clappison's Corners. COMPOSITION: interbedded sandstone and shale, mostly red. THICKNESS: 0 to 50 feet (0 to 15 m). USES: no present uses.

Thorold Formation (Middle Silurian)

STRATIGRAPHY: lower formation in the Clinton Group on the Niagara Peninsula. COMPOSITION: thick-bedded quartz sandstone. THICKNESS: 7 to 10 feet (2 - 3 m). USES: no present uses.

Neagha Formation (Middle Silurian)

STRATIGRAPHY: part of the Clinton Group on the Niagara Peninsula. COMPOSITION; dark grey to green shale with minor interbedded limestone. THICKNESS: 0 to 5 feet (0 to 2 m). USES: no present uses.

Dyer Bay Formation (Middle Silurian)

STRATIGRAPHY: lower formation in the Clinton Group on Manitoulin Island and northernmost Bruce Peninsula. COMPOSITION: highly fossiliferous, impure dolostone. THICKNESS: 0 to 20 feet (0 to 6 m). USES: no present uses.

Wingfield Formation (Middle Silurian)

STRATIGRAPHY: part of the Clinton Group on Manitoulin Island and northernmost Bruce Peninsula. COMPOSITION: olive green to grey shale with dolostone interbeds. THICKNESS: 0 to 36 feet (0 to 11 m). USES: no present uses.

St. Edmund Formation (Middle Silurian)

STRATIGRAPHY: part of the Clinton Group on Manitoulin Island and northernmost Bruce Peninsula, upper portion previously termed the Mindemoya Formation. COMPOSITION: pale grey to buff brown, micro- to medium-crystalline, thin- to medium-bedded dolostone. THICKNESS: 0 to 85 feet (0 to 26 m). USES: quarried for fill and crushed stone on Manitoulin Island. AGGREGATE SUITABILITY TESTING: $MgSO_4$ = 1-2, LA = 19-21, Absn = 0.6-0.7, BRD = 2.78-2.79, PN (Asphalt & Concrete) = 105.

Fossil Hill and Reynales Formations (Middle Silurian)

STRATIGRAPHY: part of Clinton Group; Fossil Hill Formation occurs in the northern part of the Niagara Escarpment and is approximately equivalent in part to the Reynales Formation which occurs on the Niagara Peninsula and the Escarpment as far north as the Forks of the Credit. COMPOSITION: Fossil Hill Formation - fine- to coarse-crystalline dolostone with high silica content; Reynales Formation - thin- to thick-bedded shaly dolostone and dolomitic limestone. THICKNESS: Fossil Hill Formation - 20 to 85 feet (6 to 26 m); Reynales Formation - 0 to 10 feet (0 to 3 m). USES: both formations quarried for aggregate with overlying Amabel and Lockport Formations. AGGREGATE SUITABILITY TESTING: (Fossil Hill Formation on Manitoulin Island) $MgSO_4$ = 41, LA = 29, Absn = 4.1, BRD = 2.45, PN (Asphalt & Concrete) = 370.

Irondequoit Formation (Middle Silurian)

STRATIGRAPHY: part of Clinton Group on the Niagara Peninsula south of Waterdown. COMPOSITION:

massive, coarse-crystalline crinoidal limestone. THICKNESS: 0 to 7 feet (0 to 2 m). USES: not significantly utilized.

Rochester Formation (Middle Silurian)

STRATIGRAPHY: part of Clinton Group along the Niagara Peninsula. COMPOSITION: black to dark grey calcareous shale with numerous limestone lenses. THICKNESS: 15-60 feet (5-18 m). USES: not significantly utilized. AGGREGATE SUITABILITY TESTING: PSV = 69, AAV = 17, $MgSO_4$ = 95, LA = 19, Asbn = 2.2, BRD = 2.67, PN (Asphalt & Concrete) = 400.

Decew Formation (Middle Silurian)

STRATIGRAPHY: part of Clinton Group south of Waterdown along the Niagara Peninsula. COMPOSITION: sandy to shaly dolomitic limestone and dolostone. THICKNESS: 0 to 15 feet (0 to 5 m). USES: too shaly for high quality uses, but is quarried along with Lockport Formation in places. AGGREGATE SUITABILITY TESTING: PSV = 67, AAV = 15, $MgSO_4$ = 55, LA = 21, Absn = 2.2, BRD = 2.66, PN (Asphalt & Concrete) = 255.

Lockport and Amabel Formations (Middle Silurian)

STRATIGRAPHY: Lockport Formation occurs from Waterdown to Niagara Falls, subdivided into 3 formal members: Gasport, Goat Island and Eramosa Members and an informal member (the "Vinemount shale beds"); the stratigraphically equivalent Amabel Formation, found from Waterdown to Cockburn Island, is subdivided into Lions Head, Wiarton/Colpoy Bay, and Eramosa members. COMPOSITION: Lockport Formation is thin- to massive-bedded, fine- to medium-crystalline dolostone; Amabel Formation is thin bedded to massive, medium-crystalline dolostone with reef facies near Georgetown and on the Bruce Peninsula. THICKNESS: (Lockport/ Amabel) 10 to 130 feet (3 to 40 m). USES: both formations have been used to produce lime, crushed stone, concrete aggregate, and building stone throughout their area of occurrence, and are a resource of provincial significance. AGGREGATE SUITABILITY TESTING: PSV = 36-49, AAV = 10-17, $MgSO_4$ = 2-6, LA = 25-32, Absn = 0.4-1.54, BRD = 2.61-2.81, PN (Asphalt & Concrete) = 100-105.

Guelph Formation (Middle Silurian)

STRATIGRAPHY: exposed on the Niagara Escarpment from the Niagara River to the tip of the Bruce Peninsula, mostly present in the subsurface of southwestern Ontario. COMPOSITION: Micro-crystalline to medium-crystalline, thick-bedded, soft, porous dolostone, characterized in places by extensive vuggy, porous reefal facies of high chemical purity. THICKNESS: 100 to 170 feet (30 to 52 m). USES: Some areas appear soft and unsuitable for use in the production of load-bearing aggregate. This unit requires additional testing to fully establish its aggregate suitability. Main use is for dolomitic lime for cement manufacture. Quarried near Hamilton and Guelph.

Salina Formation (Upper Silurian)

STRATIGRAPHY: present in the subsurface of southwestern Ontario; only rarely exposed at the surface. COMPOSITION: grey and maroon shale, brown dolostone and, in places, salt, anhydrite and gypsum; consists predominantly of evaporitic rich material with up to eight units identifiable. THICKNESS: 370 to 600 feet (113 to 183 m). USES: Gypsum mines at Hagersville, Caledonia, and Drumbo. Salt is mined at Goderich and Windsor and is produced from brine wells at Amherstburg, Windsor and Sarnia.

Bertie and Bass Islands Formations (Upper Silurian)

STRATIGRAPHY: Bertie Formation found in southern Niagara Peninsula; Bass Islands Formation, the Michigan Basin equivalent of the Bertie Formation, does not significantly outcrop in Ontario but is present in the subsurface in southwestern Ontario; Bertie Formation represented by Oatka, Falkirk, Scajaquanda, Williamsville, and Akron Members. COMPOSITION: medium- to massive-bedded, micro-crystalline, brown dolostone with shaly partings. THICKNESS: 45 to 160 feet (14 to 49 m). USES: Quarried for crushed stone on the Niagara Peninsula at Fort Erie, Cayuga, Hagersville and Dunnville; shaly intervals are unsuitable for use as high specification aggregate because of low freeze-thaw durability. Has also been extracted for lime. AGGREGATE SUITABILITY TESTING: PSV = 46-49, AAV = 8-11, $MgSO_4$ = 4-19, LA = 14-23, Absn = 0.8-2.8, BRD = 2.61-2.78, PN (Asphalt & Concrete) = 102-120.

Oriskany Formation (Lower Devonian)

STRATIGRAPHY: basal Devonian clastic unit, found in Niagara Peninsula. COMPOSITION: thick- to massive-bedded, coarse-grained, grey-yellow sandstone. THICKNESS: 0 to 15 feet (0 to 5 m). USES: Has been quarried for silica sand, building stone, and armour stone. May be acceptable for use as rip rap, and well cemented varieties may be acceptable for some asphaltic products. AGGREGATE SUITABILITY TESTING: (of a well cemented variety of the formation) PSV = 64, AAV = 6, $MgSO_4$ = 2, LA = 29, Absn = 1.2-1.3, BRD = 2.55, PN (Asphalt & Concrete) = 107.

Bois Blanc Formation (Lower Devonian)

STRATIGRAPHY: Springvale Sandstone Member forms the lower portion of formation. COMPOSITION: a cherty limestone with shale partings and minor interbedded dolostones; Springvale Sandstone Member is a medium- to coarse-grained, green glauconitic sand-

stone with interbeds of limestone, dolostone and brown chert. THICKNESS: 10 to 130 feet (3 to 40 m). USES: Quarried at Hagersville, Cayuga, and Port Colborne for crushed stone. Material generally unsuitable for concrete aggregate because of high chert content. AGGREGATE SUITABILITY TESTING: PSV = 48-53, AAV = 3-7, $MgSO_4$ = 3-18, LA = 15-22, Absn = 1.3-2.8, BRD = 2.50-2.70, PN (Asphalt & Concrete) = 102-290.

Onondaga Formation (Middle Devonian)

STRATIGRAPHY: correlated to part of the Detroit River Group; occurs on the Niagara Peninsula from Simcoe to Niagara Falls; contains the Edgecliff, Clarence, and Moorehouse Members. COMPOSITION: medium-bedded, fine- to coarse-grained, dark grey-brown or purplish-brown, variably cherty limestone. THICKNESS: 60 to 82 feet (18 to 25 m) USES: Quarried for crushed stone on the Niagara Peninsula at Welland and Port Colborne. High chert content makes much of the material unsuitable for use as concrete aggregate and asphaltic concrete. Has been used as a raw material in cement manufacture. AGGREGATE SUITABILITY TESTING: (Clarence and Edgecliff Members) $MgSO_4$ = 1-6, LA = 16.8-22.4, Absn = 0.5-1.1, PN (Asphalt & Concrete) = 190-276.

Amherstburg Formation (Middle Devonian)

STRATIGRAPHY: part of Detroit River Group; correlated to Onondaga Formation in Niagara Penninsula; contains Sylvania Sandstone Member and Formosa Reef Limestone. COMPOSITION: bituminous, bioclastic, stromatoporoid-rich limestone and dolostone with grey chert nodules; Formosa Reef Limestone - high purity (calcium rich) limestone; Sylvania Sandstone Member - quartz sandstone. THICKNESS: 0 to 165 feet (0 to 50 m); Formosa Reef Limestone up to 85 feet (26 m). USES: cement manufacture, agricultural lime, aggregate. AGGREGATE SUITABILITY TESTING: PSV = 57, AAV = 19, $MgSO_4$ = 9-35, LA = 26-52, Absn = 1.1-6.4, BRD = 2.35-2.62, PN (Asphalt & Concrete) = 105-300.

Lucas Formation (Middle Devonian)

STRATIGRAPHY: part of the Detroit River Group in southwestern Ontario; includes the Anderdon Member which, in the Woodstock Beachville area, may constitute the bulk of the formation. COMPOSITION: light brown or grey-brown dolostone with bituminus laminations and minor chert; Anderdon Member consists of very high purity (calcium-rich) limestone. THICKNESS: 130 to 246 feet (40 to 75 m). USES: Most important source of high-purity limestone in Ontario. Used as calcium lime for metallurgical flux and for the manufacture of chemicals. Rock of lower purity is used for cement manufacture, agricultural lime and aggregate. Anderdon Member is quarried at Amherstburg for crushed stone. AGGREGATE SUITABILITY TESTING: PSV = 46-47, AAV = 15-16, $MgSO_4$ = 2-60, LA = 22-47, Absn = 1.1-6.5, BRD = 2.35-2.40, PN (Asphalt & Concrete) = 110-160.

Dundee Formation (Middle Devonian)

STRATIGRAPHY: few natural outcrops, largely in the subsurface of southwestern Ontario. COMPOSITION: Fine- to medium-crystalline, brownish-grey, medium- to thick-bedded, dolomitic limestone with shaly partings sandy layers, and chert in some areas. THICKNESS: 50 to 100 feet (15 to 30 m). USES: Quarried near Port Dover and on Pelee Island for crushed stone. Used at St. Marys as a raw material for Portland cement. AGGREGATE SUITABILITY TESTING: $MgSO_4$ = 1-28, LA = 22-46, Absn = 0.6-6.8, PN (Asphalt & Concrete) = 125-320.

Marcellus Formation (Middle Devonian)

STRATIGRAPHY: subsurface unit, mostly found below Lake Erie and extending into the eastern U.S.A., pinches out in the Port Stanley area. COMPOSITION: black, bituminous shales. THICKNESS: 0 to 15 feet (0 to 5 m). USES: no present uses.

Bell Formation (Middle Devonian)

STRATIGRAPHY: lowest formation of the Hamilton Group, no outcrop in Ontario. COMPOSITION: soft blue and grey calcareous shale. THICKNESS: 0 to 30 feet (0 to 9 m). USES: no present uses.

Rockport Quarry Formation (Middle Devonian)

STRATIGRAPHY: part of the Hamilton Group; no outcrop in Ontario. COMPOSITION: grey-brown, very fine-grained limestone with occasional shale layers. THICKNESS: 0 to 20 feet (0 to 6 m). USES: no present uses.

Arkona Formation (Middle Devonian)

STRATIGRAPHY: part of the Hamilton Group. COMPOSITION: blue-grey, plastic, clay shale with occasional thin and laterally discontinuous limestone lenses. THICKNESS: 15 to 120 feet (5 to 37 m). USES: has been extracted at Thedford and near Arkona for the production of drainage tile.

Hungry Hollow Formation (Middle Devonian)

STRATIGRAPHY: part of the Hamilton Group. COMPOSITION: grey crinoidal limestone and soft, fossiliferous calcareous shale. THICKNESS: 0 to 6 feet (0 to 2 m). USES: suitable for some crushed stone and fill with selective quarrying. AGGREGATE SUITABILITY TESTING: No data.

Widder Formation (Middle Devonian)

STRATIGRAPHY: part of the Hamilton Group. COMPOSITION: mainly soft, grey, fossiliferous calcareous shale interbedded with blue-grey, fine-grained fossiliferous limestone. THICKNESS: 0 to 45 feet (0 to 14 m). USES: no present uses.

Ipperwash Formation (Middle Devonian)

STRATIGRAPHY: upper formation of the Hamilton Group; very limited distribution. COMPOSITION: medium- to coarse-grained, grey-brown, bioclastic limestone. THICKNESS: 5 to 45 feet (2-14 m). USES: no present uses.

Kettle Point Formation (Upper Devonian)

STRATIGRAPHY: occurs in a band between Sarnia and Erieau; small part overlain by Port Lambton Group rocks in extreme northwest. COMPOSITION: black, highly fissile, organic-rich shale with minor interbeds of grey-green silty shale. THICKNESS: 0 to 200 feet (0 to 61 m). USES: possible source of fill; possible source of material for use as sintered lightweight aggregate.

Bedford Formation (Upper Devonian)

STRATIGRAPHY: lower formation of the Port Lambton Group. COMPOSITION: soft, grey shale. THICKNESS: 0 to 108 feet (0 to 33 m). USES: no present uses.

Berea Formation (Upper Devonian)

STRATIGRAPHY: middle formation of the Port Lambton Group; not known to occur at surface in Ontario. COMPOSITION: grey, fine- to medium-grained sandstone, often dolomitic and interbedded with grey shale and siltstone. THICKNESS: 0 to 197 feet (0 to 60 m). USES: no present uses.

Sunbury Formation (Upper Devonian)

STRATIGRAPHY: upper formation of the Port Lambton Group; not known to occur at surface in Ontario. COMPOSITION: black shale. THICKNESS: 0 to 66 feet (0 to 20 m). USES: no present uses.

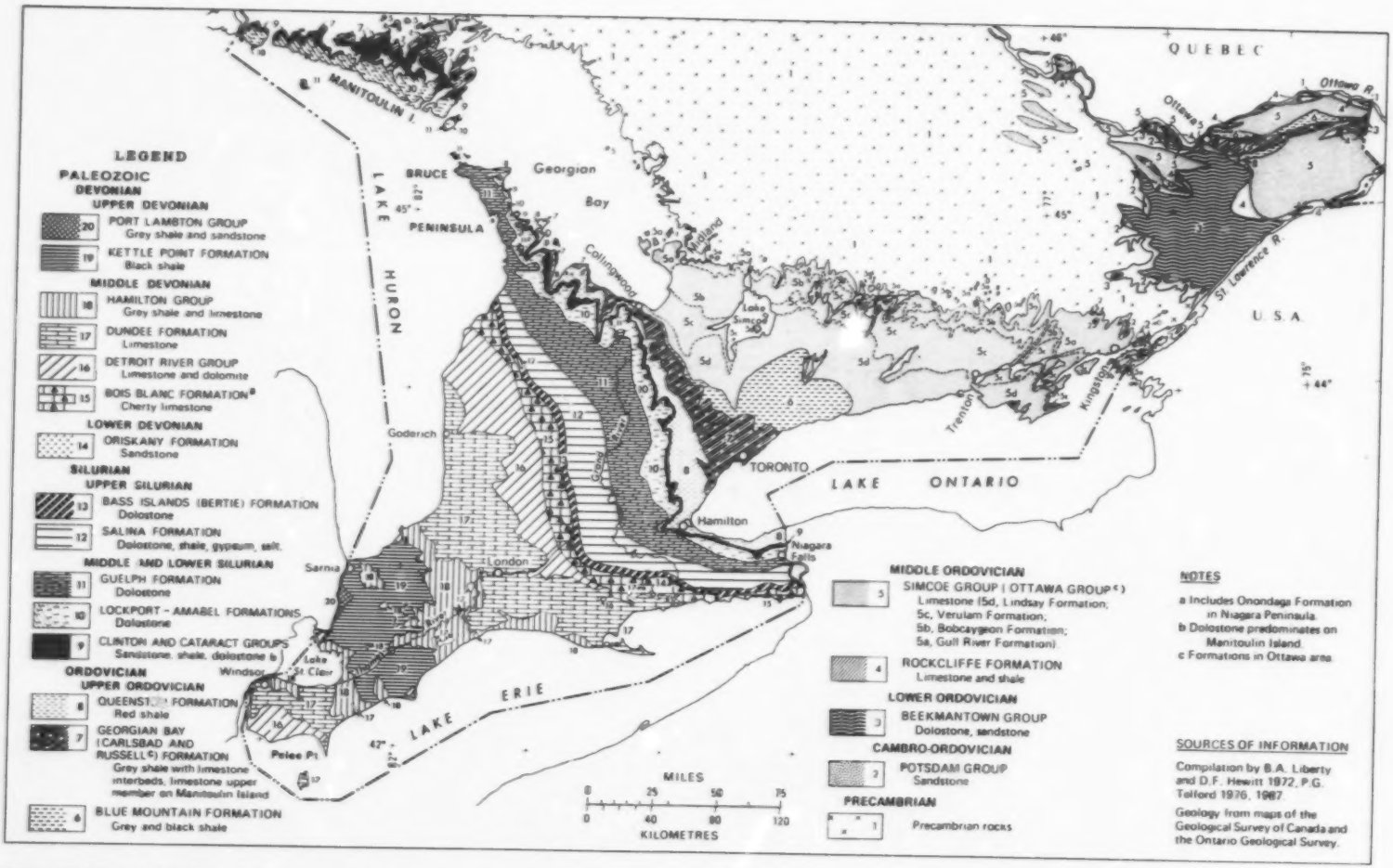

Figure D1. Bedrock Geology of Southern Ontario.

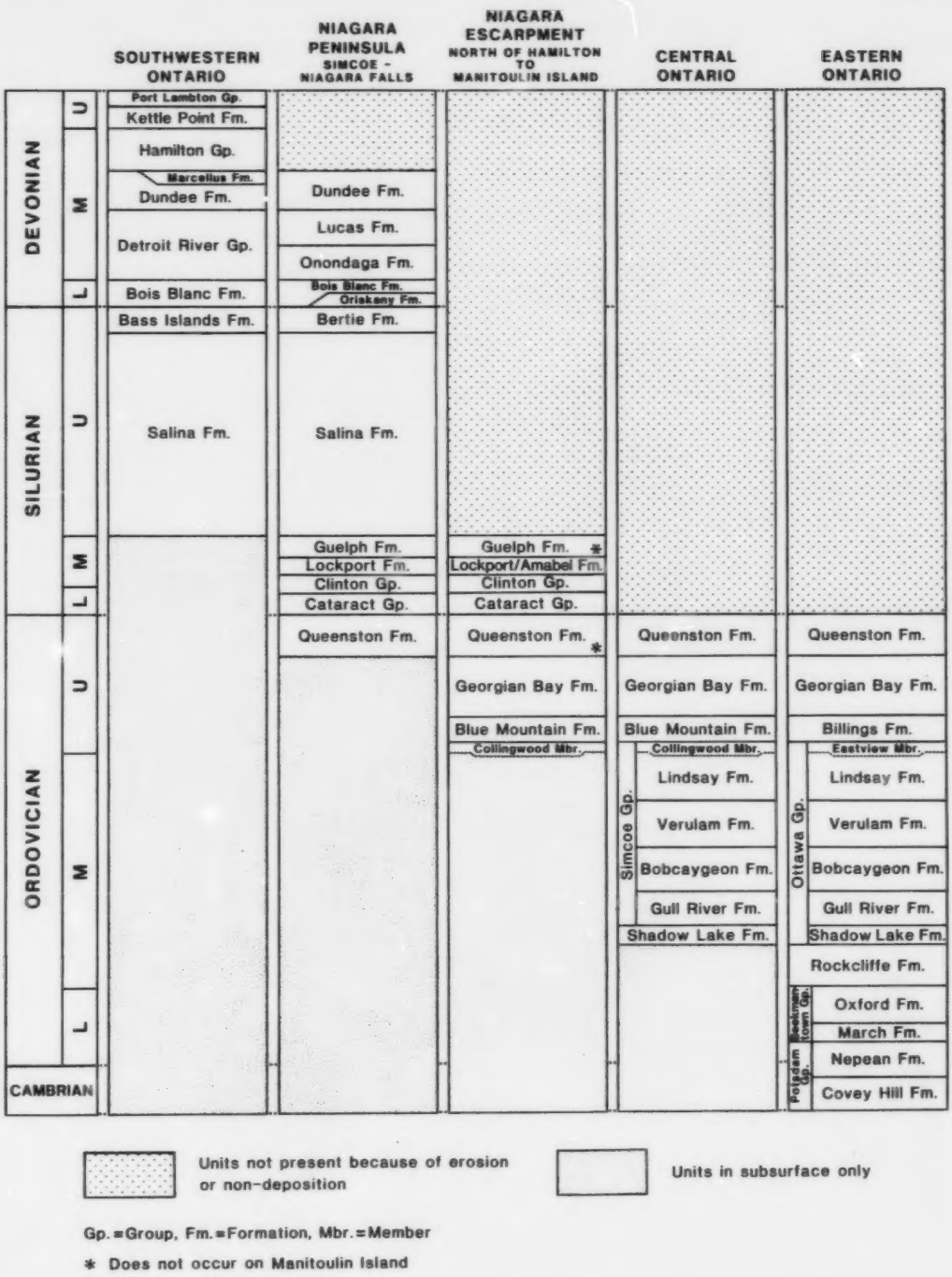

Figure D2. Exposed Paleozoic Stratigraphic Sequences in Southern Ontario
(adapted from: Bezys, R.K., and Johnson, M.D. 1988. The geology of the Paleozoic formations utilized by the limestone industry of Ontario; The Canadian Mining and Metallurgical Bulletin, v.81, no. 912, p.49-58).

Appendix E — Aggregate Quality Test Specifications

Four types of aggregate quality tests are often performed by the Ontario Ministry of Transportation on sampled material. A description of Table E1 and the specification limits for each test are given in this appendix. Although a specific sample meets or does not meet the specification limits for a certain product, it may or may not be acceptable for that use based on field performance. Additional quality tests other than the four major tests listed in this appendix can be used to determine the suitability of an aggregate. The tests are performed by the Soils and Aggregates Section, Engineering Materials Office, Ontario Ministry of Transportation.

Absorption capacity: Related to the porosity of the rock types of which an aggregate is composed. Porous rocks are subject to disintegration when absorbed liquids freeze and thaw, thus decreasing the strength of the aggregate.

Los Angeles abrasion and impact test: This test measures the resistance to abrasion and the impact strength of aggregate. This gives an idea of the breakdown that can be expected to occur when an aggregate is stockpiled, transported, and placed. Values less than about 35% indicate potentially satisfactory performance for most concrete and asphalt uses. Values of more than 45% indicate that the aggregate may be susceptible to excessive breakdown during handling and placing.

Magnesium sulphate soundness test: This test is designed to simulate the action of freezing and thawing on aggregates. Those aggregates which are susceptible to freezing and thawing will usually break down and give high losses in this test. Values greater than about 12 to 15% indicate potential problems for concrete and asphalt coarse aggregate.

Petrographic examination: Individual aggregate particles in a sample are divided into categories good, fair, poor, and deleterious, based on their rock type (petrography) and knowledge of past field performance. A petrographic number (PN) is calculated. The higher the PN, the lower the quality of the aggregate.

TABLE E1. SELECTED QUALITY REQUIREMENTS FOR MAJOR AGGREGATE PRODUCTS.

	TYPE OF TEST				
	COARSE AGGREGATE				FINE AGGREGATE
TYPE OF MATERIAL	Petrographic Number Maximum	Magnesium Sulphate Soundness – Max. % Loss	Absorption Maximum %	Los Angeles Abrasion Maximum % Loss	Magnesium Sulphate Soundness Maximum % Loss
Granular Base A	200	–	–	60	–
16 mm Crushed Type 'A'	160	–	–	35	–
16 mm Crushed Type 'B'	200	–	–	60	–
Granular Subbase B	250	–	–	–	–
Granular Subbase C	250	–	–	–	–
Granular Subbase D	–	–	–	–	–
Hot Mix – HL 1	100	5	1.0	15	16
Hot Mix – HL 2	–	–	–	–	20
Hot Mix – HL 3	135	12	1.75	35	16
Hot Mix – HL 4	160	12	2.0	35	20
Hot Mix – HL 8	160	15	2.0	35	20
Structural Concrete and Concrete Base	140	12	2.0	35	16
Pavement Concrete and Exposed Structure Deck	125	12	2.0	35	16

(Ministry of Transportation Forms 1002, 1003 and 1010)

CONVERSION FACTORS FOR MEASUREMENTS IN ONTARIO GEOLOGICAL SURVEY PUBLICATIONS

Conversion from SI to Imperial			Conversion from Imperial to SI		
SI Unit	*Multiplied by*	*Gives*	*Imperial Unit*	*Multiplied by*	*Gives*
		LENGTH			
1 mm	0.039 37	inches	1 inch	**25.4**	mm
1 cm	0.393 70	inches	1 inch	**2.54**	cm
1 m	3.280 84	feet	1 foot	**0.304 8**	m
1 m	0.049 709 7	chains	1 chain	20.116 8	m
1 km	0.621 371	miles (statute)	1 mile (statute)	**1.609 344**	km
		AREA			
1 cm^2	0.155 0	square inches	1 square inch	**6.451 6**	cm^2
1 m^2	10.763 9	square feet	1 square foot	**0.092 903 04**	m^2
1 km^2	0.386 10	square miles	1 square mile	2.589 988	km^2
1 ha	2.471 054	acres	1 acre	0.404 685 6	ha
		VOLUME			
1 cm^3	0.061 02	cubic inches	1 cubic inch	**16.387 064**	cm^3
1 m^3	35.314 7	cubic feet	1 cubic foot	0.028 316 85	m^3
1 m^3	1.308 0	cubic yards	1 cubic yard	0.764 555	m^3
		CAPACITY			
1 L	1.759 755	pints	1 pint	0.568 261	L
1 L	0.879 877	quarts	1 quart	1.136 522	L
1 L	0.219 969	gallons	1 gallon	**4.546 090**	L
		MASS			
1 g	0.035 273 96	ounces (avdp)	1 ounce (avdp)	28.349 523	g
1 g	0.032 150 75	ounces (troy)	1 ounce (troy)	**31.103 476 8**	g
1 kg	2.204 62	pounds (avdp)	1 pound (avdp)	**0.453 592 37**	kg
1 kg	0.001 102 3	tons (short)	1 ton (short)	**907.184 74**	kg
1 t	1.102 311	tons (short)	1 ton (short)	**0.907 184 74**	t
1 kg	0.000 984 21	tons (long)	1 ton (long)	**1016.046 908 8**	kg
1 t	0.984 206 5	tons (long)	1 ton (long)	**1.016 046 908 8**	t
		CONCENTRATION			
1 g/t	0.029 166 6	ounce (troy)/ ton (short)	1 ounce (troy)/ ton (short)	34.285 714 2	g/t
1 g/t	0.583 333 33	pennyweights/ ton (short)	1 pennyweight/ ton (short)	1.714 285 7	g/t

OTHER USEFUL CONVERSION FACTORS

	Multiplied by	
1 ounce (troy) per ton (short)	20.0	pennyweights per ton (short)
1 pennyweight per ton (short)	0.05	ounces (troy) per ton (short)

Note: Conversion factors which are in bold type are exact. The conversion factors have been taken from or have been derived from factors given in the Metric Practice Guide for the Canadian Mining and Metallurgical Industries, published by the Mining Association of Canada in co-operation with the Coal Association of Canada.

MAPS
NOT
FILMED

CARTES
OMISES